FRONTISPIECE. The spotted sun at its peak performance of January 30, 1937. Photographed at Cook Observatory, Wynnewood, Pennsylvania. (The black vertical line is the north and south direction.)

SUNSPOTS

AND

Their Effects

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"MAN AND THE STARS"; "EARTH, RADIO, AND THE STARS"

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To

CHARLES GREELEY ABBOT

Secretary of the Smithsonian Institution

Pioneer worker and tireless investigator in the difficult field of solar-terrestrial relationships.

FOREWARNING

THE near approach of another sunspot maximum with the accompanying interest shown by the press and the general public gives the occasion for a book on sunspots. So much has been said about the possibilities of sunspots' affecting the earth and human affairs that a candid discussion of sunspots and their effects is due the general reader who would keep himself informed of trends in science. Sunspots have been blamed for calamities and misfortunes that run the gamut from Florida hurricanes to financial panics. Is there any basis whatever for such assumptions?

Since we are all more interested in ourselves than we are in things, the book has been written from the human point of view. While statements have been qualified, various possible hypotheses have been discussed which bear upon the question of solar disturbances and affairs on the earth.

Perhaps all too long has the reading public been dependent upon the technical material in textbooks on astronomy for a knowledge of sunspots. Such textbooks which must deal only with well-established facts cannot naturally try to discuss speculative questions.

This book therefore departs from the usual type of book on science in that it frankly presents questionable material as well as the results of more completely

established facts from which the reader may draw his own conclusions with respect to inferences not yet fully established as well as to those which may be regarded as beyond debate.

As the book is intended to be distinctly popular, the more speculative material which intrigues the imagination has been presented in the earlier part, leaving the more well-established effects of sunspots upon the earth to the later chapters. The book undoubtedly raises more questions than it answers, and will, it is hoped, suggest attention to some of the less conventional aspects of the question concerning the influence of the sunspots on world events.

So many apparently serious articles have been written concerning sunspots and the business cycle that a chapter is devoted to the more plausible hypotheses that may be worth investigation. If the author appears noncommittal in his interpretation of some of the more startling presentations, it is because a scientist cannot by nature be otherwise. On the other hand, I have refrained from condemning interpretations where evidence is still scanty, for thus to condemn appears to me as unscientific as to make positive statements where complete evidence is wanting.

If the book falls into the hands of the overcredulous, perhaps a word of warning is necessary to curb hurried conclusions. One can only hope that none of the more speculative statements will be quoted except with qualifications which go therewith.

In the closing chapter I have endeavored to differentiate clearly between the several effects well established and scientifically recognized from those which are more speculative and require much further investigation before definite conclusions can be drawn. Only by such differentiation can the whole subject be clarified, with the door still open for future progress.

A scientific reader will miss technical phraseology and numerous references quoting sources which obviously are out of place in so popular a presentation. If the reading of the book stimulates a consciousness of man's cosmic surroundings and opens certain questions for serious consideration, the answers to which are yet to come, the purpose of the book will in a measure be realized.

HARLAN TRUE STETSON.

CAMBRIDGE, MASSACHUSETTS,
September, 1937.

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CHAPTER I

Ladies and Gentlemen—the Sun!

NOT since August, 1917, have such violent outbreaks been seen on the surface of the sun as have been reported this year. What influence sunspots can have on world affairs we are just beginning to find out. Many of the effects of which we are most confident are unfortunately so subtle that only scientific instruments reveal them. Yet it is a fact that there are unmistakable and often striking changes on the earth that do take place with the appearance of spots on the sun.

Take a good look at a chart representing the activity of the stock market from 1929 to date. Compare this with a similar one representing the activity of the sun as indicated by the appearance of sunspots during these same years. It will give you something to talk about when conversation lags or goes bromidic. Whether these two curves have anything to do with each other, frankly, I do not know, but here are the facts.

Sunspots were riding high in 1928 and 1929. In the autumn of 1929 there was an abrupt break in sunspot activity. The numbers of sunspots steadily fell off to near zero in 1932 and 1933. Then they began to rise.

In 1937 they made new highs with breaks both spring and fall. One does not need to be reminded of Dow-Jones averages during the last decade to be persuaded of the similarity in the action of sunspots and Wall Street. If the last decade were the only record we had

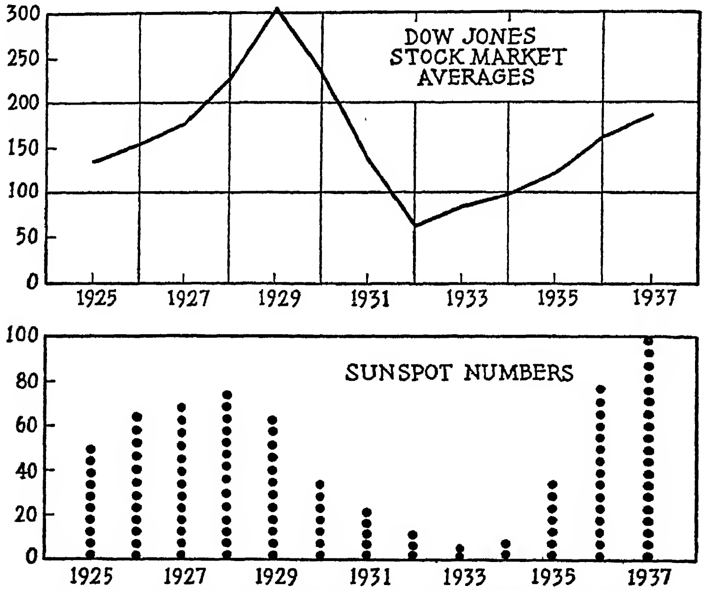


FIG. 1.—Does the stock market follow sunspots? (1937 estimated.)

of sunspot phenomena and market prices, we should certainly be enthusiastic about the relationship. Unfortunately, however, for our enthusiasm, previous decades did not show such a close correspondence. However, four out of the last five major depressions have followed in the wake of a sunspot maximum. Whether or not the similarity of these changes in the

sun and economic affairs should be taken seriously, they do give us something to think about, and a surprising lot of thinking is being done in this direction at the moment.

One does not need to be an astronomer, an economist, or a statistician to realize the simple fact that life on the earth is very much dependent upon the quantity and quality of the sun's light and heat. If there were any drastic changes in the character of the sun's output, it certainly would not be long before we found its counterpart in general conditions on the earth. While astronomers who have measured quantitatively the amount of heat from the sun received by the earth find that it varies from day to day and year to year, it does not appear to them that this variation in solar radiation alone is enough to produce any drastic changes on the earth in recent times. There are, however, subtle changes taking place in the earth that follow so closely the changes on the sun as to be a matter of scientific record and defy contention.

It is only very recently that we have been able to discover that the electrical state of the earth's atmosphere is affected by changes in the sun which accompany the outbreak of sunspots. Did you know that long-distance communication by radio on certain wave lengths has been almost impossible for several minutes at a time during the last few years? This has occurred when certain outbreaks were observed on the sun. Radio engineers have sometimes been at their wits'

end to find wave lengths or frequencies that would meet the commercial demand to transmit messages during such abnormal conditions.

Economists are too busy with world affairs and business statistics to delve into the technicalities of solar physics. Statisticians have too many worries of their own to give much thought to affairs off the earth. They are quite accustomed to blaming the ups and downs of the economic cycles on departures from the laws of supply and demand. Then, of course, there is always the possibility that some unanticipated turn in the affairs of Washington may be a bit disconcerting.

Back in the days of 1932 when traveling salesmen were scarce and one could unexpectedly find himself the sole occupant of a Pullman car for the price of a lower berth, I entered into conversation with a courageous traveler.

"What gets me," he said, "is that there are not brains enough in this country to solve this problem of booms and depressions. Why are we rushed to the limit trying to fill unsolicited orders one year, and then in a few years we can find no one to order anything, even at greatly reduced prices?"

"Has it ever occurred to you," I ventured, "that there are perhaps some fundamental cycles in Nature, the true character of which we do not understand, but which are the fundamental bases for changes in business, or psychology, or what have you, that results in

booms and depressions? We have had them as far back as history."

Now that we are well on our way toward what appears to be another great American boom we find the question still unanswered. Those who have survived what will probably go down in history as one of the greatest periods of economic depression have more than a passing interest in any serious considerations of events terrestrial or extraterrestrial that can possibly have any bearing on economic factors.

Sunspots come and go quite independently of the seasons. The sun seems to have epidemics of them. They last for four or five years and then subside and break out again. These little dark patches as seen on the surface of the sun with a telescope are indices of the kind of weather the sun is experiencing.

Ever since the invention of the telescope in the early part of the seventeenth century, traffic in sunspots has been watched continuously as they march across the solar disk, owing to the rotation of the sun which turns on its axis once in a little less than a month. While undoubtedly many astronomers must have noted that the intervals between times when sunspot traffic was most congested covered about a decade, credit for the discovery of the sunspot cycle seems to be attributed to S. H. Schwabe, who in 1843 published his findings.

Schwabe found from records of observations available to him that the interval between times of maximum traffic of these spots on the sun ranged between eleven

and twelve years. Sunspots, however, are a bit irregular in their habits, so that sometimes as short a time as nine years has elapsed between their "rush hours," and sometimes seventeen years have elapsed between periods of maximum congestion. There are many speculations as to the possible effect of these cycles of the sun on affairs on the earth and human behavior.

One of the most persistent ideas in the minds of many people is that they influence weather on the earth. Various attempts have been made, as we shall see later, to connect these solar disturbances with the passing of storms across the United States and elsewhere. There are good reasons for believing that these solar disturbances very considerably affect the earth's atmosphere, but the connecting link is not a simple one.

It is only until comparatively recent years that astronomers had any idea as to what sunspots really were. Now they know they are terrific hurricanes raging in the sun's atmosphere. These hurricanes often extend over billions of square miles and would make the most violent and devastating of tropical disturbances that was ever recorded on earth appear a puny zephyr in comparison.

It does not seem unreasonable that weather on the sun should be accompanied by changes in weather on the earth as a whole. The problem of untangling such relationships as may exist is a complex one, but it may be one of the most important problems that science can solve.

Just think of the boon it would be to business if we were really able to trace the sunspot period in the march of weather over the earth, even if we could do it only in a general way. There are so many businesses that are affected directly or indirectly by the weather that it would be one of the greatest assets to industry if science could ever solve this problem. Even the ability to predict severe or open winters in various regions of the globe would be worth millions of dollars to many communities.

Whatever the vagaries of the weather and however skeptical one may be as to sunspots' solving meteorological problems, even the most conservative scientist recognizes that the sun is after all the fundamental weather breeder. Certainly it is the principal factor in stirring up the convection currents in the earth's atmosphere that are the basis of all our weather changes.

We do know that the light and the heat of the sun undergo variations and that some of the changes appear to follow the outbreaks of sunspots. At least one prominent American scientist is convinced that by measuring variations in solar radiation, weather in certain localities can be predicted far in advance of what the official weather bureaus are doing at the present time.

Stormy weather may mean good business for dealers in umbrellas, storm boots, and raincoats, but it may ruin a bargain day for large department stores. A winter of heavy snows may skyrocket the ski business

and railroad revenue in snow trains. Cold weather in the North may cause record business for winter resorts in Florida and southern California. If sunspots or changes in the sun which accompany such disturbances are a fundamental factor in predicting mild and frigid winters, then the more we can know about the sun and its behavior the sooner we may be able to solve these problems of world weather.

Recent droughts in the Midwest may have been partly caused by man's wanton disregard of the importance of virgin forests, but there have been droughts throughout history at more or less irregular intervals, many of which have shown a striking correspondence with the sunspot cycle. Billions may be spent for flood control, but a fraction of this amount spent in investigating relationships between the sun and the earth might give us information as to when and where the next period of floods is most likely to be severe. Just as the study of earthquakes has taught us to build resistant buildings in earthquake territory at ultimate enormous savings, so a knowledge that could anticipate extreme weather conditions may well be expected to result in social adjustments that will greatly diminish losses from such causes.

However fascinating may be the far-off worlds, and however intriguing remote galaxies may appear in our big telescopes, the sun is certainly the most important star to us as human beings living on this planet Earth. After all, the sun is a typical star. It is a million times

bigger than the earth, and its trivial distance of 93,000,000 miles is rather meager where astronomical distances are concerned. We are able to live on this earth of ours because the earth's distance from the sun is such that we get just the right amount and quality of radiation from the sun to make life possible.

Have you ever thought how sensitive a creature man really is? He cannot stand for long very great changes in temperature. Life began where it was warm, presumably in the tropics, and where there was plenty of moisture. Man could not have wandered far from his original habitat had it not been for the discovery of fire. It was the discovery of fire that made it possible for him to maintain bodily comfort even during the rigorous winters of the temperate zones. The human machine is a complicated affair, and there are many other factors besides temperature for efficient running.

That changes in the sun may momentarily affect the balance of all these various factors influencing human temperament and behavior may be speculative but not at all impossible. On such a basis it will do us no harm to venture our imaginations. We may be surprised to find more basis for speculating in these directions than we have been accustomed to suppose. It may be a bit surprising to find in how many different ways changes in the sun are reflected in affairs on the earth.

CHAPTER II

Sunspots and Human Behavior

Did you wake up full of energy this morning, or is this one of those languid days when going to the office seemed a chore that you were reluctant to perform? Perhaps this whole week has been an "off" one for you. Your usual tactics, ordinarily successful, seem powerless in breaking down sales resistance. Not only you yourself but others with whom you have to deal do not seem to be up to their usual good sportsmanship. Perhaps you blame it on the weather, and maybe the weather *is* to blame. Certainly long periods of overcast and rainy weather do have a dampening effect on one's enthusiasm. Is this effect purely psychological, or is there some subtle change in the human makeup which takes place when we are deprived of the usual quota of sunshine? Whether the effect of dull weather is physiological or purely psychological may be debatable, but the practical result certainly remains the same.

Before we blame it all on the weather, reflect again. Can you not think of some sunshiny spells when in spite of what appeared to be an exhilarating day, you were still not up to your usual good form? Of course

it may happen that you have been overindulgent in a night's festivities, or viands may not have been to your liking, but checking off the calendar such days as those for which you have accountable reasons for a change of mood, have you never been conscious of periods of energy and periods of lassitude without any obvious or reasonable explanation? Most of us have our ups and downs and our own behavior patterns. We do not always work with equal efficiency.

Some time ago, Rexford B. Hersey of the University of Pennsylvania spent a year studying the employees of a large industrial organization. He checked the emotional ups and downs of seventeen apparently normal men and women. He made a record of each worker, his efficiency, his exhibition of energy, fits of temper, constructive ideas, and periods of illness. He checked the emotional attitudes of the individuals as to general hopefulness, contentment, indifference, worry, pessimism, and the like. He even studied their dominating thoughts and dreams and made a note of their physical aches and pains. He recorded their blood pressure, weight, sleep, and experiences of fatigue. Out of the records of these workers he constructed a graph of the emotional cycles of the life of each of the employees involved. It was not surprising that he found the results highly individual in their nature. Practically every subject, on the other hand, showed consistent periods of "ups and downs." During the high spots the workers did their tasks with ease and without com-

plaint. During the low periods the amount of sleep recorded was distinctly less, yet they did not appear to be tired. Lowered efficiency during the low periods was often offset to some extent by steady application to their work.

The intervals between the ups and downs were found to vary from six or seven weeks to half a year or more. It is unfortunate that Hersey did not keep his records long enough to determine whether or not the interval between the ups and downs of a given worker was consistent over a longer period of time. Probably the longer swings in human behavior are seldom noticed. The causes of these periods seem baffling, but it was evident that changes in a person's thoughts and emotions accompany some kind of changes in the bodily process. It is noticeable that in some persons of neurotic temperaments the range between their ups and downs may be disconcertingly great. The more phlegmatic type evidently respond less to such cycles of human behavior. When many individuals are affected similarly at nearly the same time, it seems possible that the long slow swings may be the result of gradual physiological changes brought about through some external factors yet beyond our control. This is something worth considerable investigation. Of course, as is the case with the foods we eat, factors favorable to one man may be less favorable to another.

Did you ever think that possibly the sun and variations in the quality and amount of sunshine may be

indirectly responsible for cycles in human behavior? It is not a new idea. Many prominent men from time to time have advanced such theories. If changes on the sun should affect the masses as such changes may affect you and me on certain days, we should have some basis for cycles in behavior over the world at large as well as in individual cases.

Some time ago Professor A. Tchijevsky, a Russian scientist, presented a startling paper at a meeting of the American Meteorological Society at Philadelphia. In this he called attention to a striking correspondence between human behavior as reflected in mass movements throughout history and the eleven-year sunspot cycle. Professor Tchijevsky is a graduate of the University of Moscow and has occupied the position of assistant at the Astronomical Observatory and collaborator in the Institute of Biological Physics and is a fellow of the Archeological Institute of Moscow. He is author of numerous papers covering widely different subjects in astronomy, physiology, archeology, and world history. The substance of much of his contributions has been translated by Mr. Vladimir deSmitt, instructor in meteorology and climatology at Columbia University, to whom I am indebted for the information about this Russian gentleman.

Believing that there was a certain parallelism in the cycles in the sun and significant events in the world's history, Professor Tchijevsky has endeavored to find a correlation between solar phenomena and periods of

energy exhibited in the mass movements of mankind. It appears that he became interested in pursuing this line of study as a result of his experiences during the World War. While in service during those harrowing years, he was convinced that increased activity on the battle fronts occurred simultaneously in many instances with the appearance of large spots on the sun. He claims that his first observation of this occurred in the middle of June, 1915, when a large group of sunspots crossed the meridian of the sun.

For the purpose of finding out whether or not there was any basis for considering a dependence of these high-energy cycles upon sunspots he undertook a special research that resulted in his belief that the greatest agitations in the masses have occurred at the times of great disturbances on the sun.

It is very easy, of course, with the records that have been kept of sunspots to obtain an index of solar behavior through at least three centuries. The difficulty came in finding a suitable index to represent the energy coefficient or the degree of excitement of human beings exhibited in mass movements.

Tchijevsky has analyzed the periods of marked disturbances of the masses into five phases which he designates as (1) provoking influence of leaders upon the masses; (2) the exciting effect of emphasized ideas upon the masses; (3) the velocity of incitability due to the presence of a single psychic center; (4) the

extensive areas covered by mass movements; (5) integration and individualization of the masses.

Assuming these factors, Professor Tchijevsky endeavors to show that at the head of the great mass movements in history one finds the greatest military and political geniuses and spiritual leaders. He believes that the exciting period may be explained by an acute change in the nervous and psychic character of humanity which takes place at sunspot maxima.

A difficulty in taking Professor Tchijevsky's deductions without reservations lies in the inability to represent the importance of historical uprisings by a numerical coefficient that appears universally applicable. His connection between cycles of agitations in the world's history and the sunspot cycle appears to lie in the fact that he finds to his liking nine such cycles in every century. On the average there are nine complete cycles in the ups and downs of the sunspot curve every hundred years. From the curve of historical events which he draws he appears to have convinced himself of remarkable correspondence between the two phenomena. Until, however, someone can arrive at a more convincing excitability quotient for mass movements than Professor Tchijevsky appears yet to have done, scientists will be reluctant to subscribe to all of the conclusions which he sets forth.

It may be of interest to note in support of Tchijevsky's hypothesis that the industrial agitation of the

early part of 1937 with its paralyzing sitdown strikes was ushered in by one of the most rapid rises in the sunspot curve that has been witnessed for two decades.

That emotional excitability depends upon temperament no one will deny. That temperament aside from inheritance may be affected by changes in environment, the quality of foodstuffs, or the abundance of sunshine may not be unreasonable. Yet, by and large, one must admit that the deductions of Professor Tchijevsky, while doubtless stimulating to the imagination, appear for the present to be rather loosely supported from a strictly scientific point of view.

In the consideration of the question of sunspots and human behavior, one would like to find at least some basis for a possible mechanism by which changes in the sun may be expected to result in changes in our behavior patterns if such exist. There appear to be at the present time two definite approaches to the problem. Present data may be insufficient to warrant definite conclusions as to the validity of the reasoning. Yet, however speculative the assumption may appear, these two lines of reasoning appear sufficiently sound on the basis of what we now know to warrant at least further investigation.

One of these concerns changes in the quantity of the sun's radiation itself and its effect upon our atmosphere and things that grow beneath it. The other concerns the quality of the food we eat which may possibly vary

with changes in the light and heat of the sun and so indirectly affect us.

Everyone knows the importance of ultraviolet radiation. The boom in the sale of health lamps for home treatment is obvious testimony to public consumption of the idea. One, has of course, to be careful in exposing himself unprotected to these lamps. An exposure of ten minutes may give one the equivalent of several hours of sunshine on a Florida beach so far as ultraviolet radiation is concerned. Perhaps if one organized social functions around health lamps with a few potted palms in the background, New York might be made to offer keen competition to the social festivities of Miami Beach in the winter.

Science is generally agreed that there is not quite any substitute for sunshine as it naturally comes to us. Nature appears to have been most intelligent in regard to the proper amount of ultraviolet light for our well-being, but she varies her dosage to mankind from year to year with variations in the sunspot cycle. Measurements of the ultraviolet light from the sun during the past ten years show that by and large the amount of the ultraviolet in sunshine has been more intense when sunspots have been most in evidence and that the ultraviolet radiation which we receive from the sun has been much less during the time when sunspots have been scarce. It is not to be assumed from this that sunspots are of themselves necessarily strong emission centers for ultraviolet light. Such is far from

the case. That the sunspots are most numerous at times when the ultraviolet light is strongest merely affords us a basis for identifying the periods through the changing character of solar radiation. It seems entirely possible that such changes as take place in the sun that result in its producing more ultraviolet light so stir up the solar atmosphere that sunspots are naturally concomitant circumstances.

Fortunately here on the earth most of the ultraviolet light from the sun is absorbed in the earth's atmosphere. Just enough appears to get through this blanket of air to give us the needed quota for health and happiness if we take full advantage of our outdoor opportunities. It appears that most of the sun's ultraviolet light is stopped by the oxygen molecules some twenty-five miles above the surface of the earth. For a considerable region above this level much of the ultraviolet seems to be used up in converting oxygen into ozone. As the oxygen atoms combine to make ozone under the stimulus of the sun's radiation, a screen is formed which prevents the more penetrating rays of the sun from reaching the earth. If it were not for this protecting layer of ozone, we could never stand being exposed directly to the sun's rays. There is so much ultraviolet light coming through space from the sun that it would do wholesale damage to plants and animals if it ever reached the earth undiluted.

Now, as the sun goes through its cycles of behavior and the ultraviolet light becomes more intense, more

ozone cuts out more and more of the ultraviolet light. The result is that just enough of these ultrablue rays come through to the earth to make life possible. Nature has been very clever in balancing these factors. Or, to express it another way, out of the evolutionary processes that have been at work on the earth for millions of years the forms of life that still survive are those that are adapted to that average quality of sunlight that now reaches the earth. If we should receive much less of the ultraviolet radiation than we do, we should all die off of rickets. If we should receive much more, we should be unmercifully burned.

Speaking of sunburn, have you ever noticed that some summers you seem to burn much more readily than others? That seems to be the impression of many habitual sunbathers. Is this due to variation in the ultraviolet light in the sun as it varies from year to year? Actual measurements made every day at the Mount Wilson Observatory of the Carnegie Institution of Washington have revealed changes of as much as 20 per cent in the intensity of ultraviolet light. If the sun should maintain its highest output of ultraviolet light for any considerable period, it seems not at all impossible that physiological effects would follow. Perhaps we should be overstimulated. If, on the other hand, a deficiency of ultraviolet light should continue indefinitely at the lower level which it had in 1932, we might very well reach a low state of vitality unless we offset the deficiency by recourse to

ultraviolet-light treatments or vitamin pills. The mechanism by which ultraviolet radiation is absorbed by the human system and converted into the all-essential vitamins is still a puzzle for biologists to solve.

The dependence of the functioning of the ductless glands upon vitamins is one of the most intriguing problems of medical science today. The relationship between the performance of the endocrine glands and human temperament seems now to have been definitely established by many workers in the fields of medical science. Just how the all-important secretion from the ductless glands depends upon the radiation we receive from the sun, the kind of air we breathe, and the foods we eat no one yet knows, but from study along these lines we may look for some of the most notable contributions of science to mankind in the coming decades. The work of Dr. Walter B. Cannon and his collaborators at the Harvard Medical School has so definitely established the connection between the secretion of the adrenal glands and the ability of the animal to run or fight that we are led to believe that cycles in temperament and ability to meet emergencies may be very definitely associated with the mysterious workings of our endocrines.

Since the paraphernalia of the physical laboratory has entered the fields of biology and medicine, it has been more and more apparent that the human being is a veritable electrical dynamo. With every act or thought, currents of electricity travel throughout the

miles of nerve fibers quite as really as the electricity flows over the transmission lines of a municipality from a central powerhouse. While the food we eat is the fuel supply for running our biological powerhouse, it appears that the endocrine glands are the control rooms of the power system. These control rooms may be very sensitive to the external stimuli of our environment.

Recent experiments in Germany have been made in an endeavor to find out what connection if any there may be between the electrical conditions of the air we breathe and our physiological and mental reactions. With every breath we take we quite unwittingly absorb electrical charges of the tiny little particles of air that enter our respiratory system. For some strange reason, we know that the molecules of air are charged with electricity, some positively and some negatively. These charged air molecules are familiarly known in the laboratory as ions.

Professor Dessauer of Frankfort once subjected a number of patients alternately to positive and negative ions. His experiments were carried on in an air-conditioned room where the scientist had complete control over the number and character of these ions without any knowledge on the part of the patients concerned. He startled the world with a report that he had observed a change of blood pressure and of mental attitude that accompanied the change in the atmosphere from a positive to a negative charge. A

superabundance of positive ions developed a feeling of fatigue, dizziness, and headache on the part of the patients. When the positive ions were slowly removed and negative ions substituted, fatigue and headache gave way to exhilaration. Persons with high blood pressure were relieved, according to his findings, by the inhalation of negative ions in 80 per cent of the cases investigated.

Professor Yaglou of the Harvard School of Public Health made similar investigations which seemed to corroborate the German scientist's findings. Other experimenters in this country, however, who have endeavored to repeat the investigation have failed to find any definite evidence for a change of mood or physiological process with changes in the atmospheric ions. When scientists disagree, it would appear that the subject is still debatable.

Now, whether the ions in the air we breathe change periodically with the sunspots or not we do not know. We do have evidence that a heavily ionized region in the earth's atmosphere 100 miles up varies its ionic content with activity on the sun. This, as we shall discuss later, was found out through radio investigations. If the ions in the upper atmosphere change periodically with the sun, it would appear not unreasonable that the ions in the lower atmosphere of the earth which we breathe might also be subject to fluctuations in character and number with the solar cycle. It is only within the last few years that day-by-

day counts have been made of the ions in the lower atmosphere on a sufficiently systematic basis to give us the necessary data for comparison with the solar cycles. When observations of another decade have accumulated, we may be able to answer the question as to whether atmospheric ions depend in any way upon sunspots.

A sufficient number of observations have been made to show that there is a diurnal variation in the numbers of positive and negative ions in the air of the earth's surface. They have been found to rise near midday when the sun's radiation is strongest. They also show a seasonal rise, with the largest numbers occurring in the summer season, which would again appear to indicate that sunshine may be an important factor in their distribution.

If, now, changes in the character of sunshine, such as more or less ultraviolet light, affect the vitamin content of the human body with a consequent impact upon the sensitive endocrines, and if also it shall become established that changes in the atmospheric ions through some similar mysterious processes are accompanied by physiological changes and consequent mental outlook, we have a connecting chain whereby human behavior could respond to the sunspot cycle. One cannot, however, overemphasize caution in jumping at conclusions, however attractive the speculative hypothesis may be. Until some of these ifs are definitely dismissed by more positive statements, science can do

little more than keep an open mind and devise experiments for helping to establish or discredit this alluring but tentative argument.

Now, the possibility of changes in solar radiation and the electrical condition of the earth's atmosphere affecting plant growth, which in turn may respond with various degrees of vitamin content, is another question. That the vitamin contents of the foods we eat affect the action of our endocrines and thus indirectly influence our temperament and mental outlook seems to have some basis. The effect of variation in the quantity and quality of sunlight upon vegetation is a subject which well deserves our attention. Let us see what connection science has already been able to establish between the records of growing things and the sunspot cycle.

CHAPTER III

Sunspots and Growing Things

STROLLING through the woods the other day, I came across a tree stump, all that remained of some monarch of the woods after the huge trunk had been sawn through and removed. Stooping to examine the interior structure of this once-living thing, I could not refrain from counting those fascinating tree rings. There were just 144 of them. While this was not a very old tree as some trees go, there was a peculiar fascination in reminiscing on what had happened during the 144 years in this plant's history and what effect the changing environment had had on the growth of this particular oak.

It was evident that this particular tree's environment had changed many times, and by environment we mean conditions more favorable or less favorable to growing things. How do we know? Because the tree rings were sometimes spaced close together; then there would be an interval of wide spaces between the rings, then narrow spaces again. What was it that had happened during the last 144 years that found response in the rate of growth of this particular tree?

Of course each year it had encountered the northern winter and the following summer, and each sequence of seasons left its appropriate ring. What was happening, however, during those periods when for several years at a stretch the rings were widely spaced and the tree grew more rapidly? Did it mean more moisture and then severe rainfall? Or were there changing qualities of the sunshine, some of which were more favorable for encouraging the enlargement of the trunk? Probably something of both.

All this brought vividly to my mind the results of a lifetime's study of one of America's most distinguished men of science, Professor A. E. Douglass of the University of Arizona. Professor Douglass is an astronomer and director of the Steward Observatory at Tucson. But while interested in the stars, Professor Douglass has always been equally interested in life and growing things. He is one of the few astronomers who spent some time at the Lowell Observatory at Flagstaff, Arizona, studying the canals of Mars, canals which the founder of that observatory consistently interpreted as indications of tracks of vegetation on our neighboring planet—tracks that had been laid out by intelligent beings. The same keen observing eye that was able to delineate those difficult Martian canals was equally keen in observing the tree rings in the Arizona forests.

He noted that sequences of periods of rapid growth were followed by periods of retarded growth and then

rapid growth again. His discerning eye noted on the average that there were, in many cases, ten to a dozen rings separating intervals of more rapid growth. Believing that the growing conditions under which the trees survive might be varying with the sunspot cycle, he began an intensive study counting tree rings

FIG. 2.—Tree rings register solar cycles through the centuries. (*From Earth, Radio, and the Stars.*)

by the thousands to discover if his assumption could be verified.

As specimen after specimen of the Arizona pines, the redwoods of California, and the giant sequoias were brought into his workshop, Dr. Douglass' laboratory requirements soon outgrew the observatory at his command. So the university offered him larger quarters for a tree-ring laboratory. The problem of analyzing the spaces between rings by the thousands would have been a discouraging one for a man with-

out the persistence, patience, and scientific enthusiasm of Professor Douglass. To cope with the problem he devised a novel scheme for analyzing the periods in the growth of trees. By means of an elaborate optical contrivance he could take the tree-ring pattern of a single specimen or a dozen specimens and in a relatively short time discover intervals of eleven years, seven years, twenty-three years, and longer to which variations in tree growth had definitely responded. In this country he found the sunspot cycle nearly always split into two maxima. From examination of trees in German forests, he found that a single maximum was more common but not universal.

While there were wide variations in the growth patterns of trees taken from different forests, there was a similarity in the space intervals between periods of most rapid growth throughout the whole southwestern territory. As his analysis progressed, it was more and more evident that the eleven-year sunspot period and other periods related to it were reflected in this biological survey.

It was evident that in the tree trunks there were indelibly recorded conditions of weather and climate long before mankind ever thought of establishing weather bureaus or meteorological stations. Where tree rings were crowded close together year after year, it was obvious that there had been great droughts in the Southwest that had retarded growth. Here and there he caught the records of vast forest fires that

had swept the primeval woodlands and suddenly dwarfed the growth. But he learned to make allowances for these catastrophic interruptions whose telltale patterns were clearly recognized.

The idea that the analysis of tree rings, betraying periods of droughts and rainfall over centuries, might ultimately lead to the possibility of long-range weather forecasting was a persistent stimulus to the worthwhileness of his researches. Furthermore, if the tree-ring patterns reflected the solar cycle, was not here a definite indication that sunspots and biological behavior, at least so far as tree growth was concerned, were intimately associated? In order to establish definitely connections with the sunspot variations, it was obviously necessary that he know not only the age of the tree but the identical year corresponding to any particular ring. So he had to build up a tree chronology to carry from the present far back through the centuries.

Beginning with the outmost ring of a tree just cut down and counting toward the heart of the individual, the ring pattern could be definitely identified with the calendar. With sufficiently old trees, the time spacing of special ring patterns could be carried over from living trees to more ancient specimens whose date of felling was unknown. The presistence of the ring pattern definitely showed cross dating or cross identification, as Dr. Douglass calls it, and by such a scheme he was able to carry back the record of the tree rings

for more than 3000 years. In a succession of trees in Arizona he has an actual record of 1900 years; and in the case of the sequoias, 3200 years.

At times there would be gaps in his chronological sequence. There seemed to be no specimens available which would connect the ancient with the more modern period. Somewhere, thought Professor Douglass, in the ruins of some ancient pueblo of the Southwest, there must lie timbers cut from trees of just the years that were required to bridge the gaps.

But where to go for such specimens was a problem. Professor Douglass' contributions to chronology had already brought him into high esteem among archeologists, and archeology now lent its hand to help in the solution of the problem.

Scattered among the ruins of the ancient Hopi villages were specimens and fragments of pottery of all sorts. Archeologists were more or less familiar with the evolution of pottery patterns. So Professor Douglass thought that if he could learn to read the chronology of pottery, he might gain information as to the particular ceramic pattern that must have evolved during the years of his gaps in the tree-ring sequence. Then it would be only a question of letting fragments of such pottery guide him to the proper sites of the early pueblos, and he would have a fair chance of unearthing timbers there that would show tree-ring patterns for those periods where data were lacking.

So Professor Douglass mastered the archeological art so far as pottery was concerned and then proceeded on his romantic search. With eager delight he at last found a pueblo wherein lay fragments of the type of pottery sought. True to his expectations, he found there the ancient timbers that concealed the coveted chronology. Within those old timbers were the tree-ring patterns that overlapped both sides of the gap that had caused so much anxiety. Thus, after long patient years, this veteran of science was able to complete his chronological cycles. For the happy ending to one of the most fascinating chapters in science, the Research Corporation bestowed upon Dr. Douglass its prize award of $2500.

His constant searches for new specimens have taken him all over the world. For more ancient relics he has examined Egyptian sarcophagi, there to find cycles of rainfall and growth dating back to the Pharaohs.

During his studies, one thing bothered our astronomer-archeologist most exasperatingly, and that was that in the tree rings that he had dated between 1645 and 1715, he found very little indication of the eleven-year sunspot cycle that was supposed to have had a maximum during that interval.

One day early in 1922 Professor Douglass' morning mail brought a letter from Professor Maunder of the Royal Observatory in Greenwich, England. In this letter Professor Maunder told Professor Douglass that he had been searching into early records of sunspot

observations with some surprising results. This search of the English astronomer had revealed that a great dearth of sunspots had been observed during the entire period from 1645 to 1715. Maunder knew nothing of Douglass' difficulties but merely wished to convey to him the information of this remarkable discovery in sunspot data. He ventured to remark to the Arizona scientist that if there were any real connection between his tree-growth theory and the sunspot cycle, he should have found evidence lacking as to sunspots in his tree-ring records between 1645 and 1715. Thus we see how a strange failure of sunspots to appear during the middle of the seventeenth century actually corroborated Douglass' findings at a time when he nearly gave up the idea of the connection between sunspots and tree rings on account of an apparently unexplainable discrepancy.

However skeptical some scientists may have been in regard to Professor Douglass' theory of sunspots and tree growth during the early days of his investigation, there are few well-informed scientists today who have not accepted the connection. The obvious inference of all these years is that since tree growth responds readily to rainfall and drought, periods of sunspots have been related to periods of abundant or deficient moisture in the great Southwest.

Many investigators have endeavored to trace records of rainfall in recent years with numbers of sunspots. The result has left many inconsistencies. The

problem is most baffling. Is it possible that other factors than moisture alone have entered into the rate of growth of trees and all growing things? With years of equal precipitation, is it possible that more sunshine or more ultraviolet light in the solar radiation may have been an added stimulation to growth? It would appear reasonable that a tree sufficiently sensitive to have

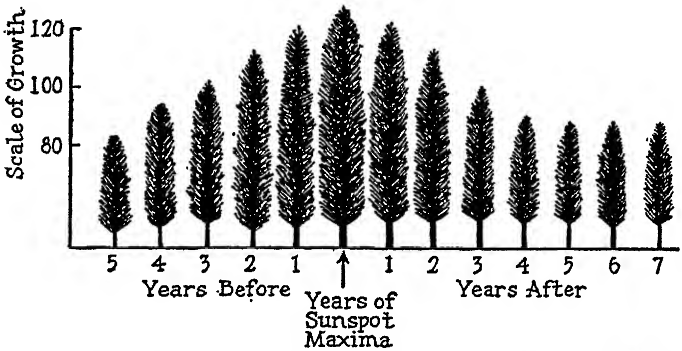


FIG. 3.—Trees show most growth when sunspots are most numerous. (Data based on Douglass' investigation of growth in German forests covering over seven solar cycles.)

recorded each year's growth in its ring pattern should have unconsciously taken into account every factor favorable and unfavorable for its continued existence.

Today many fascinating experiments are being carried on in biological laboratories and plant experiment stations testing the effect of different qualities of light and radiation upon growing things.

When potato sprouts growing in a dark cellar bend toward the light, it is a very particular kind of light to which they respond. Not all the colors of the

spectrum of daylight are equally effective. If the window panes were made of red glass, there would be no response at all. If we had a blue-glass window, on the other hand, we should find that they bent very markedly toward the blue light. These are the conclusions reached some time ago at the Smithsonian Institution by Dr. Earl S. Johnson, who is a wizard in divining the habits of plants as they respond differently to light of different colors.

It appears that different qualities of light are needed at various stages in a plant's growth to develop it normally. The red end of the spectrum appears to be particularly necessary in the germination of certain seeds. Take the so-called "dormant" lettuce seeds for example. Soak them in water for twenty-four hours. If they have had the normal quota of daylight, they will germinate. On the other hand, if you keep them in total darkness, they will not germinate at all. Suppose, now, we try growing these seeds underneath glass window panes of different colors. We shall find that they will grow equally well if the window panes are red, orange, yellow or yellowish green. When we try green, greenish-blue, and blue window glass, there is no germination at all. These are the remarkable discoveries made not long ago by Mr. Louis Flint of the Bureau of Plant Industry at the United States Department of Agriculture.

If there are changes in the sunspot cycle so that the quality of sunshine is altered as well as its intensity,

it would appear that the growth of plants, at least of some plants, may be seriously modified. Perhaps the quality of sunshine is quite as important as the amount of rainfall in the kind of crops we grow.

Many attempts have been made to try to discover if the quantity of vitamin D produced in plants is closely related to the same kind of light which appears to be responsible for the production of vitamin D in animals. Ever since the effect of ultraviolet light in preventing rickets in animals has been known, scientists have been experimenting to find if a similar effect results in plants subjected to ultraviolet radiation.

It is a rather slow process determining the vitamin D content of growing things, for not only must the plants reach the food stage, but they must be fed to animals, and animals watched in regard to their tendency to develop rickets on a given diet. But scientists are painstaking and tireless workers, and they have already accumulated many facts pertinent to the problem. It has already been found that the tissues of some plants which ultimately have little or no antirachitic properties are rendered much more potent when exposed to some source of ultraviolet light.

Not all plants behave alike. Cabbage, for example, one vegetable which appears to have no power whatever to prevent rickets, was found to exhibit no response to an ultraviolet treatment. On the other hand, alfalfa grown in Arizona and cured in bright sunshine developed antirachitic powers which could

not be found in the same plant cured in darkness. Evidently vitamin D, or the all-essential ergosterol that scientists like to talk about, is increased in the plants by exposure to ultraviolet radiation.

Some plants are very sensitive indeed to this light of very short wave length. Take the tomato plant, for example. Its sensitive leaves are seriously injured by an exposure to an ultraviolet health lamp. With an overdosage they shrivel and die. It is generally supposed that such ultraviolet light as comes from the sun and gets through the earth's atmosphere is not injurious to growing things. But it appears reasonable that even such small variations in the ultraviolet light of the sun as appear to follow the sunspot cycle may produce real effects in tender plants. Thus it is possible that the changing quality of sunlight from year to year may have something to do with the varying vintages of our foodstuffs. Is the wheat grown on the farms during a sunspot maximum richer in vitamins or slightly different in its food content than the wheat grown during a sunspot minimum? Of course much would depend upon the conditions of the soil, precipitation, and temperature during the growing season.

Every wine merchant knows that there have been years of exceptional vintages and other years when wines have been uniformly poor. A New York wine importer listed the quality of five different varieties of wines for the last twenty years. In order to see if there were any connection between the varying quali-

ties and the sunspot cycle, I assigned a score of five for what was regarded as the most excellent vintages and adopted zero for the score for very poor wines. Intermediate qualities were assigned proportionate values. Then, averaging the scores of the various products over the years, I made a chart of the results. It is interesting to note that there is a rise and fall on

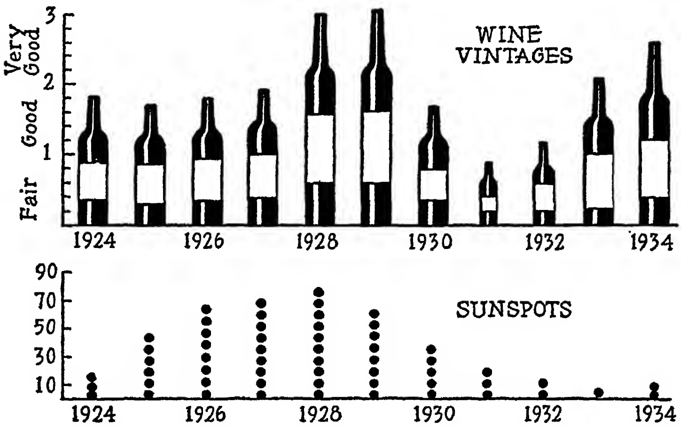


FIG. 4.—A decade of wine vintages compared with sunspots. Height of flask drawn proportional to quality of vintage.

this vintage chart occurring twice during the last two sunspot cycles.

In a study of periods of solar phenomena published by Professor H. Fritz during the last sunspot maximum, he presents a table of sunspots and wine harvests from such data as were available from the year 188 on. From 1626 to 1883 the material available is quite complete. During the twenty-four sunspot maxima occurring in the seventeenth, eighteenth, and nine-

teenth centuries, nineteen remarkable wine harvests happened each time within two years of a sunspot maximum. Only four especially good vintages did not come within these relatively narrow limits. In my tabulation of the last twenty years, the years of the many sunspots (1928 and 1929) were marked by exceptionally fine wine harvests, while the period immediately preceding and following revealed unusually poor scores. At the previous sunspot maximum, however, in 1917 and 1918, the harvests were not remarkable. Possibly some aftereffects from the World War may indirectly account for the inferior quality of this particular vintage, or is this but an exception to prove the rule?

There seems to be enough evidence relative to the connection of sunspots and harvests of one sort or another to lead one to believe that a more systematic investigation of the problem is worth time, money, and effort. By further experimentation now in process it may be possible to trace the production of vitamin D in the different vintages of food products and in the conditions under which the plants grow and mature. Of course there are other and equally important vitamins contained in agricultural products that have a marked effect upon the consumer.

Recent experiments have indicated that persons deficient in vitamin A have great difficulty in seeing objects at night. Some statistical studies would lead us to believe that night blindness on the part of the

automobile driver may be somewhat mitigated by more attention to the diet of the operator of the vehicle with respect to vitamin A. Besides vitamins A and D there are also vitamins B and C which appear to be protectors against deficiency in digestive processes, loss of weight, and general vigor. Then there is the vitamin C, one of the earlier vitamins to be discovered which was found to be the missing element in the food of sailors who contracted scurvy. Vitamins A, B, and D resulted from the long and arduous work of Doctors McCollum, Mendal, and Osborne and other prominent specialists covering a decade of the most painstaking investigations from 1912 to 1922. To just what extent these several vitamins may be dependent upon the qualities of sunshine we have to find out. We have seen that vitamin D is undoubtedly produced in animals as a direct result of exposure to ultraviolet light upon the individual. Then there is already definite evidence that certain vegetables respond somewhat similarly to sunshine.

The part of sunshine in health cannot be overestimated. When dressed in our abbreviated bathing suits we lie three-quarters naked beneath the summer sun shining brightly overhead, we are certainly building up reserve of vitamin D. During long winter months when the days are short and the sun is low, we miss these health-giving violet rays of summer. Perhaps the summer of 1938 with its high sunspot maximum will afford us an unusual storehouse

of vitamin D if we avail ourselves of our vacation opportunities.

The possibility that the harvest of the next two years may yield foods unusually rich in vitamin qualities is something to speculate about. The dependence of plants upon certain kinds of radiation for the production of vitamins and the dependence of human temperament and psychology upon the vitamin content of our diet are problems for the biologist and physiologist to solve. The question of the change in the quality of sunshine through definite periods or cycles is of interest not only to the astronomer and the meteorologist but to students of society and economics as well. The problem of the reality of the connection between the sunspots, human behavior, and the economic cycle is one which challenges the cooperative efforts of all these scientists. Some who delight to venture in new territory and cross conventional fields may hope to contribute to the answer to the question.

Meanwhile, one large food industry sufficiently interested in the problem is consigning to science a sample of at least one product of each year's crop with the hope that when some of these investigations have been completed, we may be one step farther toward finding the relationship between the sun and our economic affairs.

With the remarkable results that have been found in tracing the sunspot cycle in the growth of trees, it is not surprising that some have sought to find a

relationship between the numbers of fur-bearing animals and variations in sunspots. Taking the number of pelts appearing in the records of the Hudson Bay Company, remarkable variations have been found in the number of pelts of the fox, the lynx, and the rabbit with a period of ten or eleven years' duration. From 1850 to 1900 nearly every peak in the number of rabbit pelts corresponded quite closely with a minimum in the number of sunspots.

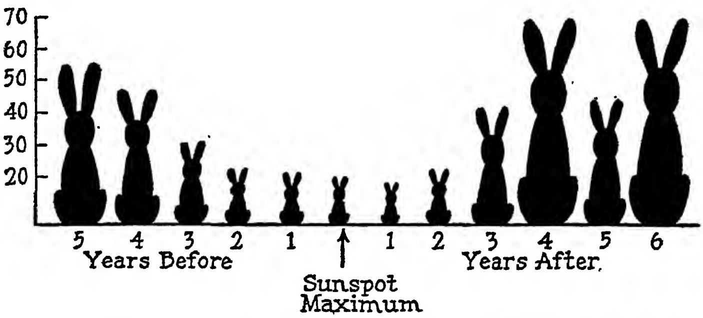


FIG. 5.—Height of figure shows relative number of pelts taken years before and years after sunspot maximum. (Data based on five sunspot cycles.)

If sunspots have anything to do with rabbit population, and sunspot years have been favorable for tree growth, one might wonder why rabbits appear most numerous near sunspot minima and most scarce near sunspot maxima. Perhaps the trappers, stimulated by sunspots, have been more energetic in depopulating the rabbit world during years of sunspot maxima, or perchance other animals who are natural foes of the little four-footed creatures thrive best at sunspot maxima. The natural life cycle of the animal, the

character of the food which it eats, and its coefficient of self-preservation and self-propagation are other factors that enter into the picture.

The fact that there is a recurrence of more or less definite intervals in the numbers of fur-bearing animals of approximately the sunspot period is suggestive of the wide variety of problems with which one may be concerned in tracing solar and terrestrial relationships.

Then of course there is the question of more or less definite periods in epidemics which exist both in the animal and the plant world, as in the world of human beings. A natural life cycle in the microorganism might be perhaps more immediately affected by changes in solar radiation and ultraviolet light than the cycles of population in Mammalia. The presence and absence of such epidemics would certainly be reflected in the population of the individuals critically subject to such periodic epidemics.

A one-to-one correspondence between any biological variations and sunspots would doubtless be of inestimable help in furthering a connection between solar and terrestrial relationships. Such a simple correspondence, however, is not to be expected, considering the many variable factors involved.

On the other hand, a cyclical variation in biological affairs which does not necessarily at all appear commensurate with the sunspot period could, nevertheless, depend upon the eleven-year solar variation. We cannot dismiss the possibility of the connection merely

on the grounds of a difference in length of period of the two classes of phenomena. The solar cycle of eleven years impressing itself upon some other natural cycle could result in a variation that has for its period neither that of the sun nor that of the natural period of the terrestrial phenomena under consideration but a combination of both.

One of the most interesting experiments relative to the effect of ultraviolet radiation and the performance of glands was made not long ago on a pair of monkeys in the London Zoo. It appears that the pair were apparently normal in every respect, but all attempts at mating were ineffectual.

It was finally decided to make use of scientific treatments of ultraviolet radiation and watch results. Results were forthcoming. Not only was mating consummated, but the little lady involved soon produced both twins and triplets. Evidently there is much to be learned relative to the importance of ultraviolet rays in the functioning of hormones. The idea that secretions of the ductless glands may be stimulated or controlled by variations in the exposure to ultraviolet rays appears to be substantiated and opens up many possibilities for further experimentation.

Not long ago evidence was presented that the phenomenon of migration is associated with a phase change in the reproductive cycle. Investigations at the University of Wisconsin have shown many close relationships between the migration of birds and the recognized sunspot cycle.

CHAPTER IV

Sunspots and Radio

"HELLO, London—New York calling. Stock Exchange, please. Mr. Jones wishes to talk to Mr. Smith."

"Hello, Mr. Smith? What is the quotation on—what? Operator! Operator! *Operator!* I was talking with London. What?"

"Sorry, you've lost them."

"Can't you tell me when I can get a connection again?"

This might be a frequent occurrence in a transatlantic telephone call if it were not for the ingenuity of radio engineers in overcoming all but the insurmountable difficulties which occasionally occur in radio transmission due to the sudden eruptions on the sun. Careful checks must frequently be made on transmission conditions over certain frequencies or wave lengths in order to make possible overseas communication.

This is why telephone companies the world over are beginning to study the sun and sunspots in cooperation with astronomers. Such difficulties in long-line communication are not new, for, as far back as the

invention of the telegraph, sunspots have at times seriously interfered with cables and telegraph lines on account of the heavy electric currents that have been induced in them as the result of some solar outburst. To a large extent engineers have learned how to sidestep many of the difficulties.

The advent of the wireless and the radio telephone brought some new problems when communication lines led through the atmosphere rather than through copper wires. During the last year or two on several occasions, scientific publications have reported complete fade-outs of radio communication from England, South America, and other countries when unusually vicious explosions have taken place on the sun. Fortunately such complete interruptions seldom occur at any one time on all frequencies or wave lengths in the communication channels assigned by governments for commercial purposes. When sunspots interrupt the traffic on an assigned frequency, be assured that experts know it. Although they have no idea of the nature of your conversation, they can tell on suitable telltale apparatus when Old Sol starts interfering with the connection. Without your knowledge the radio waves that carry your important message may be shifted to another frequency that will get your call through.

According to records kept at the National Bureau of Standards, there have been reported 115 occasions since the present rise in sunspots when conspicuous fade-outs have occurred in high-frequency radio trans-

mission. On ten of these occasions the disturbances were so intense as to wipe out practically all communication on certain high frequencies for an interval of a few minutes to an hour or more.

In about half of all the reported cases, remarkable explosions on the sun have been seen to coincide almost exactly with the time of the beginning of the radio fade-out. Not only is the radio affected, but the earth's terrestrial magnetism is also simultaneously disturbed. The fact that radio communications fade out most noticeably in regions which are directly under the sun is very strong evidence indeed that something happens on the sun that is responsible for the effect.

With such a striking commercial aspect to the situation, astronomers at the Mount Wilson Observatory, finding it impossible to watch the sun every minute of the day, devised special motion-picture apparatus which would photograph these solar eruptions whenever they occurred. This special solar camera is now started every day at sunrise and operates continuously, requiring very little attention until it is shut off just before sunset. This new outfit went into operation in May, 1936.

Already over two thousand feet of motion-picture film has been obtained, recording faithfully every movement of the sun that revealed itself to the motion-picture camera. During fifteen remarkable eruptions on the sun which have been recorded thus far, there have been five cases when the time of eruptions was

the same time as the beginning of a radio fade-out. In six cases the solar disturbances preceded the effect on the earth from two to twelve minutes. No radio fade-out is definitely known to have preceded a solar eruption with which it might be connected.

All these observations indicate that great outbursts of hydrogen and calcium on the surface of the sun are particularly responsible for sending some kind of radiation to the earth, which, traveling with the speed of light, penetrates so far into the earth's atmosphere as to wipe out momentarily though completely all radio communications, except those which are transmitted at very low frequencies.

Just what happens when you talk by radio or send a wireless message is still a mystery to the average man, but a radio engineer has a fairly clear picture of how your voice travels to London or how your favorite broadcast program comes to you from the other side of the world.

Far above the earth, far above the record flight of the *Explorer* II, when Major Albert Stevens soared fourteen miles into the stratosphere, lies the radio ceiling of the atmosphere, some 200 miles high. This radio ceiling is daily created for your convenience and mine by the radiation of the sun shining upon it. The ultraviolet light coming into the thin atmosphere at such high altitudes is so intense that we could never hope to survive in its direct rays were it ever possible to gain such altitude. This ultraviolet light shining

upon the molecules of oxygen and nitrogen partly discomposes these molecules as it knocks off little electrons from the atoms, creating the so-called ions.

Physicists picture all matter as made up of positive and negative charges of electricity. When these positive and negative charges of electricity occur in equal numbers in the molecules of gas, the molecule is said to be neutral. Then it is not conductive of electricity. When, however, one of these molecules is hit by the death-dealing rays of ultraviolet radiation from the sun, it is split up into separate positive and negative particles and becomes ionized, in the language of the laboratory.

Completely surrounding the earth is a spherical shell of these electrified ions that we have come to call the ionosphere. In this ionosphere is the radio ceiling from which waves sent out from broadcasting antennas are reflected back to earth as the tennis ball is reflected back from the ceiling of the squash court when you have served a high one.

Imagine a squash game played where the rules required every shot to be made to the ceiling of the court. By proper attention to your serving you might be able to place the ball anywhere you liked in the court by hitting it against the ceiling. So, by a proper choice of frequency, the radio wave may be sent off from the sending station near New York, hit the radio ceiling, and bounce back again in the vicinity of London, carrying your conversation along with it, or it may make several bounces en route with the identical

results. Now consider the difficulties that would be introduced into your squash game carried on in such fashion if the ceiling of the court were constantly being raised and lowered. You would need the eye and the agility of a juggler to maintain your score.

This is rather a crude picture of what happens when disturbances on the sun upset the ions in the ionosphere. The radio ceiling goes bouncing up and down, and the radio waves reflected from this ceiling, therefore, sometimes fall short of their destination, and sometimes they overshoot.

To carry the tennis analogy a little further, the ceiling of the court should be made of a coarse wire mesh. While bouncing up and down, the spaces in the mesh sometimes grow larger and smaller. With such a disturbance going on, occasionally the ball may penetrate through the ceiling and be lost to the players. This is what often happens to radio waves of very high frequency. You can see why the communication engineers must be constantly on the job to furnish a wave of the proper size that will not go through the net and will come down at the desired destination.

A knowledge of the existence of the ionosphere all came about with the invention of radio, and now laboratories scattered in various parts of the world are cooperating through the use of radio waves in exploring the world of the ionosphere.

A ship sounds the depth of the ocean by sending a sound wave down through the water and measuring

the length of time it takes to come back from the ocean bottom into the receiver of the apparatus on the ship's hull. Knowing the speed with which sound travels through water, a ship's captain can thus determine the depth.

In a similar manner, radio engineers send pulses up through the stratosphere till they hit the radio ceiling, bounce back again, and are caught in the receiving apparatus. The time that it takes the radio wave to go to the ionosphere and back is carefully measured. Knowing that these radio waves travel very nearly with the velocity of light, they can tell the height of the ionized ceiling at any moment by measuring the very small fraction of a second consumed in the passing of the wave to the ionosphere and back. Measurements made at all hours of the day and night and every day in the year bring to light many interesting facts.

We know, for example, that on the side of the earth turned toward the sun where the ionosphere is continually exposed to the sun's rays the ceiling is much lower than on the side of the earth away from the sun. This accounts for the great difference in the way in which radio waves travel in the daytime as compared with darkness. The shorter waves or the high-frequency waves are the ones which are often best suited for daytime transmission.

Just as there is a day and night effect, so also is there a seasonal effect. During the long summer days in the northern hemisphere the top of the atmosphere is much

more heavily ionized than during the shorter days in the winter season. The radio ceiling, therefore, is lower in the summer than in winter.

When, during sunspot maxima, solar activity results, as it generally does, in greater output of ultraviolet light, the ionosphere is more heavily ionized than during the years of sunspot minima. This results in a long undulation of the radio ceiling as it rises and falls over an eleven-year period. When a sunspot is suddenly formed, or a violent eruption takes place in the atmosphere of the sun, there is a burst of energy sent toward the earth, which, hitting the ionosphere, may create all sorts of disturbances. Thus we see how radio communication is very intimately linked with sunspots.

Could we visualize the ethereal substance of the ionosphere as we visualize the surface of the ocean, we should find times when terrific storms were raging in the ionosphere. Ions and electrons are being hurled hither and yon as though some great electrical wind played upon its surface, creating vast waves literally miles high. At times the crest of these waves will be blown off into spray with no regular reflecting surface for radio communication at all. As the disturbances on the sun subside, these undulations in the ionosphere quiet down, and we have more normal conditions in this ocean of the air.

Every night in the private laboratory at my home in the suburbs of Boston, radio waves from the broadcasting station WBBM, Chicago, are making a con-

tinuous record of transmission conditions between Chicago and Boston, via the ionosphere. When the height of this radio ceiling is most favorable for reflecting radio waves from the Chicago station into the vicinity of Boston, they push the pen well toward the top of the chart on which the continuous record is being written. When, owing to disturbances on the sun and other causes, the height of the ceiling is less fortunate for transmission conditions, then the pen slides back toward the bottom of the chart, leaving its graphical record of poor reception.

For ten years now we have nearly continuous records of the way in which these radio waves have performed nightly as they have traveled from Chicago to the ionosphere and from the ionosphere back to the receiving apparatus in Boston. Charting carefully the ups and downs of the pen trace, we have found that from the time sunspots turned their peak in 1928 and 1929, receiving conditions very much improved. With the outbreak of sunspots again, the strength of the Chicago waves has, in general, diminished. This led to the conclusion that, broadly speaking, radio reception from the distant stations in the broadcast band was better at times of few sunspots and worse at times when there were most sunspots.

There is some indication, however, that there may be more than one critical height of this reflecting layer for producing best reception over this 900-mile path as we tune to the frequency of 770 kilocycles. Using

our tennis court analogy, one might bring the ball into the desired court by bouncing it from a ceiling placed at two or more definite heights, depending upon the initial conditions under which the ball leaves the racket. Let us suppose, for example, that if the radio ceiling is 100 miles high, radio reception over a given track is favorable for a given frequency and that the same might also be true for a height of 50 miles but that at 75 miles the reflections are unsatisfactory for the particular distance in question. During a sunspot maximum the energy of the sun's radiation tends to push down the ionosphere so that even under night conditions it is around the 75-mile level. Our estimates may not be accurate under many conditions, but they will serve the purpose for illustration.

As the sunspots subside, the positive and negative charges will tend to unite so that radio waves have to go higher to find a sufficient number of electrons or ions to bounce back. The radio ceiling under such circumstances may effectively rise to 100 miles, and we have distinctly improved conditions for receiving the radio waves from a distant station. As sunspots break out again, down comes the effective height of the ceiling, bringing again poorer conditions. If there is unusual activity on the part of the sun, the ceiling may be pushed even lower, approaching the 50-mile level, whereby again conditions for reception are more favorable. With too great sunspot activity, then, we may actually witness an improvement in radio reception,

when, generally speaking, we should expect inferior quality. If solar activity is great enough to force the ceiling below the 50-mile level, the conditions may become very poor again. Thus we see that the picture is a particularly complicated one so that it is not always possible to predict without qualifications that radio reception will be uniformly poor with many sunspots and uniformly good when sunspots are few. All of this, however, only emphasizes the intimate connection between the sun and the behavior of our radio reception when we tune in for our favorite program.

There is another rather interesting phenomenon which occurs if you live within about 50 miles of your favorite broadcasting station. In the daytime the ionosphere is so low owing to the direct action of the sun's rays that you get very little energy from the broadcasting antenna by way of the sky. The reception which you do get is by means of a wave which travels from the sending station over the ground to your receiving set. When night comes on and the sun's rays have been removed from the ionosphere over your region, the radio ceiling rises, and the waves which shoot skyward from the broadcasting antenna may come back to your set in such a way as to interfere seriously with the wave traveling over the ground to your receiver. The result will be "mushiness" and confusion. This was actually observed in many localities during the sunspot minimum of 1932 to 1933, when, generally speaking, we should look for unimpaired

reception from long distances. This is the reason why you often have poorer reception from some near-by stations during years of too few sunspots. When you listen to a station 1000 miles away, you enjoy your program by means of the sky wave only because the ground wave very quickly loses its energy as it travels over the ground.

The diagram showing the variations in the numbers of sunspots during the last cycle from 1923 to 1933

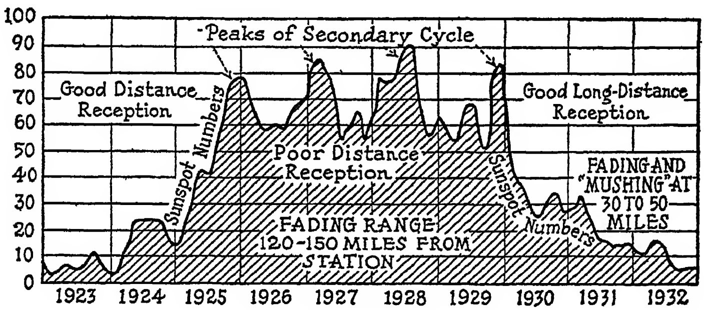


FIG. 6.—Variation in sunspots from 1923 to 1932 showing observed change in quality of radio reception. The vertical scale gives sunspot numbers.

carries legends based upon observations and serves very generally to predict the kind of reception that you may expect to receive as the sunspots come and go. It is well to bear in mind these cosmic factors that enter so importantly into the conditions of the ionized region of the upper air that makes all broadcasting possible.

One feels fairly confident in predicting that over the next two or three years disturbances in the ionosphere

will render the quality of reception over a distance very unfavorable. The same conditions, however, which produce trouble in long-wave reception actually help very much on short-wave reception. This means that you are better off, in general, in listening to programs from remote regions on short waves over the next few years than is likely to be the case in 1942–1943 when sunspots will again be near the minimum. But it is in 1942 and 1943 that you may expect unusually good conditions for listening to the commercial broadcasting stations in this country that tune to frequencies of 550 to 1500 kilocycles.

With the vast improvements in radio sets in recent years it has been possible, by minimizing high outdoor antennas, to avoid much of the trouble due to static, which causes irregular crackles in the receiver. This is fortunate at the present time, for it is when sunspots are most numerous that it has been found that static disturbances are usually greatest.

Static is due to irregular discharges of electricity between different regions of the atmosphere existing at different electrical levels. The most conspicuous exhibition of this occurs when you have your radio set turned on during a thunderstorm. But even when no thunderstorms are in evidence, static is present to a greater or lesser degree and particularly so during the periods of turbulent movements in the ionosphere accompanying violent disturbances on the sun. Even the rotation period of the sun that brings a given dis-

turbed area into line with the earth once every twenty-seven days has been traced in radio static.

While knowledge of the sun has helped us to understand the vagaries of radio, you will understand that radio is one of the most useful tools for learning more about what happens on the sun and how disturbances there affect the ions in the upper air. Perhaps some day, even though the sky is cloudy, we shall have a very good idea as to what is going on in the surface of the sun by the way in which the radio waves behave. Unlike the telescope, radio apparatus does not go out of commission just as soon as the sky is overcast, for the electric waves pass through the clouds as easily as ordinary daylight comes through window glass.

CHAPTER V

Sunspots and Business

IF Major Angas, Colonel Ayres, Roger Babson, or other noted investment counselors had predicted the American boom of 1937 on the basis of the behavior of sunspots during the last ten years, they could not have been more successful in their prophecies. If we look at a chart of the numbers of sunspots during this interval and compare them with a chart of business activity for the same years, we have so striking a parallelism that to anticipate the top of the next sunspot market would be to anticipate the peak of the present rise of business.

If we look back over previous solar cycles, we do not often find the correspondence between sunspot numbers and business activity so pronounced. Otherwise, of course, we should have undoubtedly determined the laws of solar and business relations long before and guided our behavior accordingly. But there have been many things which have distorted the relationship.

If we look back, however, over many periods of booms and depressions and compare them with the solar cycle, we find that four out of the last five major

business depressions have followed in the wake of a sunspot maximum. The average interval between a period of the high, or maximum, in sunspots and the low of the depressions immediately following has been about two and a half years. Going farther back and comparing the curve of solar activity with business activity, we see that five of the last seven major de-

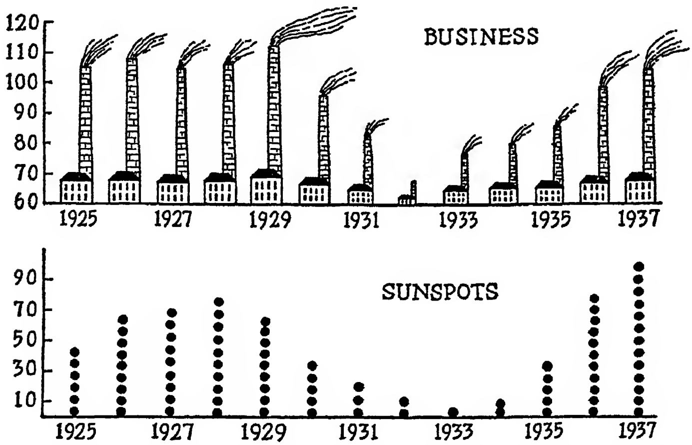


FIG. 7.—Business activity has followed sunspots through the last decade. Height of chimney is drawn proportional to business index published by *The Annalist*.

pressions have occupied a similar relationship with sunspots. Of course, this may be a pure coincidence, but we ask ourselves, *Is* it mere coincidence?

The idea that sunspots may have something to do with business is not altogether a new idea. Back in 1878 the economist W. S. Jevons presented to the British Association for the Advancement of Science a paper in which he endeavored to show evidence for a

very definite cycle in economic crises with an average interval of between ten and eleven years. He determined this interval from what he regarded as "unquestionable collapses" occurring between 1721 and 1887. This he regarded as very near the average of the sunspot cycle which he took to be 10.45 years. Since he could "see no reason why the human mind, in its own spontaneous action, should select a period of 10.45 years to vary in," he postulated that there must be some outside phenomenon related to the solar cycle that was timing the industrial waves of prosperity and depression. His argument was that since the variation in the number of sunspots was accompanied by corresponding variations in collapses, sunspots must have something to do with their occurrence.

Believing that collapses formed the fundamental basis of the business cycles and that they were dependent on crops, he tried to find a similar pattern in the fluctuation of agricultural prices. If sunspots affected crop production and crops were dominant in economic affairs, then the chain of events connecting sunspots with business might be demonstrated.

Now, Dr. Warren Persons has shown that while there is a very high correlation between agricultural yields and the physical production of crops in the United States, there is no corresponding correlation with total values. Every American farmer knows how often bumper crops yield such low prices that his margin of earnings is often actually less during years of

such high agricultural yields than during years of more meager supply when prices are correspondingly higher.

In 1914 Professor H. L. Moore, writing on "Economic Cycles, Their Law and Cause," propounded another theory. He stated that there was an eight-year cycle in the annual rainfall in the United States which corresponded to a similar cycle in wholesale prices. Thus, to Professor Moore, weather was the key to agriculture, which in turn affected the ups and downs of trade in general. Dr. Persons differs from Professor Moore and insists that his own studies do not warrant the belief that the prices of agricultural commodities in themselves exhibit the periodical movements that reflect the changes in general business conditions.

Failure to find a sound basis of argument for a connection between agricultural yields and periods of prosperity and depression has led to the search for other cyclical causes. Could it be that changes taking place in the sun affect human psychology more intimately than they do agriculture and that periodic waves of pessimism and optimism are at the foundation of business behavior?

No one doubts that business cycles depend to a very large extent upon one's mental attitude. Dr. Ellsworth Huntington of Yale is a persistent believer in the idea that changes in the sun affect not only the earth but even human health and behavior. His studies led him to believe that there is a certain dependence of mental attitude upon health. One's mental power, according

to Dr. Huntington, is at its best about one year after maximum health. He assigns four years as the interval between a degree of maximum health and general business conditions. Professor Huntington bases his index of health upon the inverse death rate, a procedure which some have regarded as questionable. Nevertheless, with such a system of more or less elastic "lags," it appeared possible to make many adjustments between the business curve and the sunspot curve that would allow for many of the discrepancies and bring them much more closely into alignment.

Assuming that some psychological explanation of business fluctuations is a plausible one, then the question becomes one of finding a relationship between cycles in business psychology and cycles of cosmic origin, if the hypothesis of sun and business is to be vindicated.

The idea that one's mental attitude depends upon physiological functioning is sound science. The possibility that small fluctuations in the quality of sunshine, its known electrical effects upon the earth, and its atmosphere may find response in physiological changes is one of the most alluring fields of speculation.

The idea that business cycles follow cycles in human behavior and the psychology of the masses is not altogether new. As far back as the early part of the nineteenth century John Stuart Mill offered a psychological explanation for business fluctuations. Ever since that time this has been one of the outstanding theories over

which there has been endless debate. If the effects of the changes in the sun's behavior can be traced in the habits and actions of the masses, then indeed we should have some basis for business cycles following sunspots.

Near the close of the last depression (November, 1934), the *Quarterly Journal of Economics* published an article on solar and economic relationships by two young men who, after discussing many of these earlier theories, endeavored to show a rather close relationship between sunspots and industrial activity.

One of these men was Felix I. Shaffner, an instructor in economics at Harvard University and a former student of mine in astronomy at Harvard. The other was Carlos Garcia-Mata, an Argentine sent to this country by the Argentine Republic on a fellowship for special study. More lately Mata has been attached to the Argentine Embassy at Washington. The investigation undertaken by these two men was aided by two grants from the Committee on Research in Social Sciences of Harvard University. This article, which summarized their findings, has caused considerable comment during the last two years. It has appealed to the imagination of those desperate for an explanation of the ups and downs of the business cycle and at least has the merit of removing some of the blame for the dilapidated condition of the world's financial affairs from the seats of government.

The article, which in fairness it must be stated appeared as a "preliminary report," has received both

favorable and unfavorable criticism, but their report must stand on its own merits. However guarded are their statements, it is perfectly evident that their brief is for a relationship between solar cycles and economic affairs. Whatever one's attitude toward the interpretation of the report, it is fitting that the *Journal* should have published what no one can question was a conscientious effort at an investigation of an old problem with additional and more up-to-date material. Once again it focused attention on relationships between cosmic and terrestrial affairs.

On the assumption that agriculture did not play an important part in general economic conditions and that the earlier idea of Jevon's that connected crops, sunspots, and economic affairs was invalid, Shaffner and Mata took the index of total industrial production in the United States, extending from 1876 to 1930. As this curve of business affairs did not follow very convincingly a similar curve which they made by charting the areas of sunspots observed throughout the same interval, they took the differences of the sunspot areas from year to year with a four-year moving average. The resulting graph displayed the tops of the sunspot curve in such fashion as to make a fairly close fit with the curve of industrial production. They also tried making charts of solar faculae, the little white clouds that frequently appear on the surface of the sun in the neighborhood of sunspots, and found a certain correspondence between the numbers of these solar disturbances

and manufactures. Every astronomer knows, however, that any graph of variations in faculae will be very similar to the graph of variations in sunspots, for the two are intimately associated.

Again, they took the measured values of solar radiation as determined by the Smithsonian Institution in Washington. They called attention to the fact that while the solar curve in their estimation coincides with

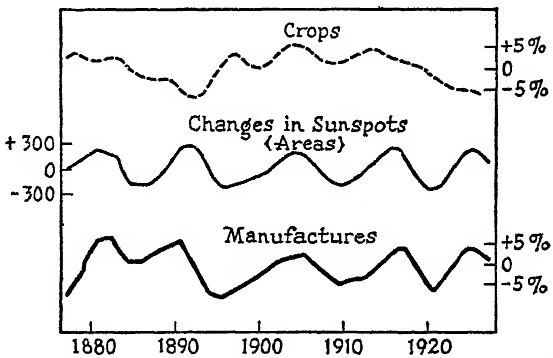


FIG. 8.—Manufactures appear to follow changes in sunspots. Crops do not. (*After Mata and Shaffner in Quarterly Journal of Economics.*)

all the major business depressions, there are two short-period business panics that appear to show no relation to the solar curve. One of these is the Rich Man's Panic of 1903–1904 which occurred while sunspots were well on their way toward a maximum; and the other is the brief depression of 1913–1914 which may be referred to as the prewar depression. This prewar depression, by the way, occurred just at the end of sunspot minimum. The new solar cycle was rapidly

getting into action in 1914–1915. If the intensity of solar radiation rather than the sunspots themselves affect mundane affairs, a slightly different slant on the situation is to be inferred.

On the basis of the Smithsonian curves of solar radiation, Shaffner and Mata call attention to a notable diminution of the solar radiation received during these years and a corresponding drop in the average temperature all over the world. The diminished solar radiation and the consequent drop in the earth's temperature during 1903 and 1904 they did not attribute to changes in the sun itself but rather to the eruption of Mount Pelée.

There does appear to be scientific evidence that dust and ashes sent high into the upper atmosphere may screen some of the radiation from the sun so that for months afterwards the earth does not get its full quota of solar energy. In June, 1912, there was a notable eruption of Mount Katmai in Alaska. The measured values of solar radiation following this catastrophe might therefore be expected to be less than normal. Shaffner and Mata would therefore explain the discrepancies between their curve for business and their curve of solar radiation as due to the faulty transmission of solar energy through the volcanic dust caused by Pelée and Katmai. It is obvious that the eruption of these volcanoes could hardly be blamed for the economic ills of 1903 and 1904, or 1913 and 1914. Whether or not Shaffner and Mata's explanation of the lack of accord of

business with measured solar radiation during these periods is correct, one must give credit for the ingenuity of the idea.

Probably the chief value of their contribution is the discussion of the possibility that cosmic and terrestrial relationships may ultimately affect economic cycles. Certainly no one-to-one relationship may be relied upon to portray variations in any single business index. Thus far it would appear that one cannot predict with certainty any major economic change as a simple function of visible changes on the surface of the sun.

While it is a fact that intervals of the business cycle do not always correspond to similar intervals in sunspot activity, there is not sufficient negative evidence for entirely discrediting the connection. There are so many factors which may accelerate or retard the peak of business activity with respect to a solar stimulus that one could scarcely expect an exact correspondence to hold for any great length of time. The relation of one business to another and the dependence of production upon the general market, together with the fears and consequences of government regulation, could do much to shift the peaks and the valleys of the business curve with respect to any curve of solar phenomena. Perhaps in primitive times a man's prosperity was affected more promptly and acutely by variations in nature. In the complexities of modern civilization there are many thinkable reasons why we cannot more easily trace solar and economic relationships. We cannot, however,

deny the important place of the sun in human affairs.

The invention of vast systems of grain elevators, cold storage plants, and the rapid movement of commodities through the improved transportation facilities of modern times would certainly appear to be factors that could shift the maximum and minimum of business activity with respect to any natural cycle. Thus several years might well elapse between a cosmic change and a corresponding change in the economic affairs of the world of sufficient consequence to attract attention. Just as the introduction of the Federal Reserve System postponed the evil day for the closing of smaller and less sound banks during the last great depression and yet could not ultimately prevent a financial crisis, so doubtless many factors introduced through human ingenuity or deviltry may have widely separated the peaks of prosperity and the valleys of depression from the disturbing factors fundamentally responsible for the changes involved.

When one is comparing curves of business activity with changes taking place on the sun, the surprising thing is not that there are many discrepancies in the period of fluctuations but that the trend of these two phenomena has been so much the same in the last decade. Everyone knows that there is often a considerable interval which elapses between an effect and a cause. A heavy storm rages over the Atlantic Ocean. A day or two later we get the waves from it along the

New Jersey coastline. The sun sends us its maximum seasonal heat in the northern hemisphere around the twentieth of June, but this half of the earth on the average is the hottest about three or four weeks later. You see, the accumulation of heat goes on even after the days have actually begun to shorten, and it takes

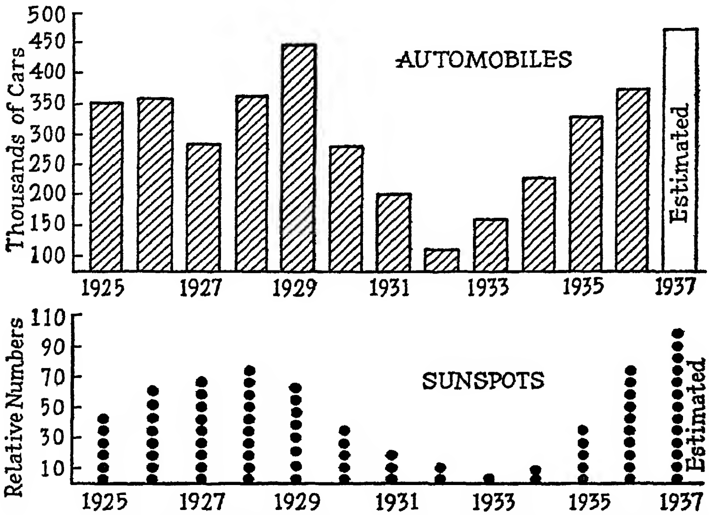


FIG. 9.—Automobile production shows variation with sunspot numbers, 1925–1937.

time for the earth to arrive at its maximum surface temperature as a result of the long, warm days of early summer.

Obviously some businesses are much more sensitive to economic conditions than others. Consumer goods respond more promptly to buying psychology than do the heavier industries. Perhaps the purchase of automobiles reflects as quickly as any commodity the

effect of changes in buying psychology—the ability to buy on delivery or the hope of paying on an installment basis. Look at the chart of automobile production during the last decade. There is a striking resemblance between this and the numbers of sunspots. The minimum of automobile production occurred in 1932, and the minimum of sunspots in 1933. As production anticipates consumer demand, changes in the production curve would probably precede any remarkable change in the numbers of cars bought. It is at least striking to see the rapid recovery in automobile production of 1933–1937 and the rapid recovery of sunspot activity during these same years.

A chart representing the valuation of building awards by years shows that the minimum fell in 1933, the very year of sunspot minimum. The following year the total valuation in new contracts awarded was doubled, and there was a doubling in the number of sunspots recorded. The climb in the building trades, however, has been more gentle than that in automobile production. It is obvious that after the low point, new cars will be bought before new buildings are erected.

Perhaps another way of gauging optimism and one's enthusiasm for venturing in new undertakings may be found in the number of new businesses incorporated per year in a given state. The departments of state in the commonwealths of New York, New Jersey, Delaware, and Massachusetts have kindly furnished me with the number of new incorporations each year

within the respective boundaries from 1900 to January 1, 1937. Of course, all of these states show a continual increase in the number of new incorporations each year, and some sort of allowance must be made for this trend before any comparison can be made with solar

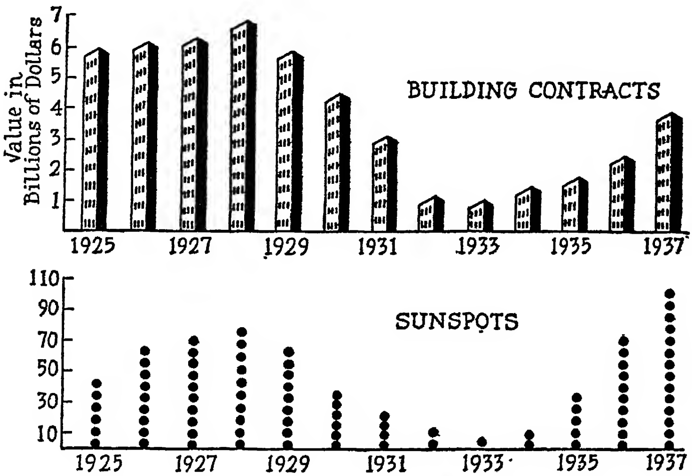


FIG. 10.—Building contracts seem to follow the present sunspot cycle. (Value for 1937 is estimated.)

phenomena. Furthermore, it is often shortly after periods of depression, when even important executives have been thrown out of going organizations, that new companies have been formed. One could, therefore, hardly expect that a year-to-year comparison with sunspots would show much or would mean much. It seemed worth while, however, to take the average yearly increase of new business incorporations in the several states for a five-year period around sunspot

maxima and for a similar five-year period around sunspot minima. The figures were prepared after grouping with respect to the sunspot curve without any reference to value. The results proved somewhat surprising.

In New York State the average yearly increase in new incorporations for a five-year period around sunspot maxima was 1069. The average yearly increase for the number of new incorporations during the five-year period around sunspot minima was *minus* 63. The minus sign, of course, indicates an actual falling off in the rate of increase during the years of sunspot minima.

For the state of New Jersey, the average increase in the number of new incorporations for a similar period grouped around sunspot maxima was 239, whereas the corresponding value around sunspot minima was *minus* 32.

In the state of Delaware the average yearly increase of new incorporations for five-year intervals around sunspot maxima was 386, whereas around sunspot minima it was a *minus* 286.

In the state of Massachusetts with a much smaller number of corporations, one might not expect the data to be sufficient to be significant. However, examining again the five-year periods around sunspot maxima, the average yearly increase in new incorporations in the Commonwealth of Massachusetts was 71, whereas during similar periods grouped about sunspot minima there was a deficiency of *minus* 38.

In these several instances all of the data were treated in precisely the same way and covered the last three sunspot cycles. If the number of new incorporations of business concerns is an index of activity, optimism, and new ventures, then there is remarkable consistency in the several instances in favor of sunspot maxima as a wholesome factor for business and industrial health.

Another way to check business health with sunspots is to look at the shady side of the picture. This may be approached from the point of view of business failures. If we examine the total number of business failures year by year in the United States as published by Standard Statistics and find the average yearly increase in the numbers of such failures over five-year periods around sunspot maxima and around sunspot minima, we should expect that if there is anything in the sunspot theory, a large increase in the number of failures would be shown for periods of sunspot minima and a smaller increase in business failures take place around sunspot maxima.

Treating the data in exactly the same way as we did in the number of new incorporations, we find that the average yearly *increase* in business failures for the whole United States over the five-year period around sunspot minima is 1399, whereas for sunspot maxima there is an average yearly *decrease* in the number of failures of 572. Thus we see that business failures tell the same story as new incorporations, so far as we may be concerned with sunspots. Again, the data have

included the last three completed sunspot cycles, extending from 1900 to 1935.

Whether or not business psychology or industrial activity is actually affected by the solar cycle or the business cycle for the last thirty years merely shows a remarkable coincidence with activity on the sun, one cannot yet definitely say. If such a strong coincidence as has existed during the last three decades, for which our data are more or less uniform, may be trusted to persist, then we should perhaps be wary at the approach of the next peak of prosperity which, judging from the sunspot cycle, should put in its appearance in 1939 or 1940.

Certainly by 1939 we can expect sunspots to have passed the peak of maximum activity and start the slide downward to the next sunspot minimum in 1944. While one may not venture to predict, at least it will be of interest to watch developments in the economic world during the next few years while sunspots turn the top of their market and sag again toward the zero level.

Since writing the above paragraphs, a college president has called my attention to the fact that gifts from benefactors of certain small institutions that depend largely upon subscriptions of small denominations show a record of gifts month by month and year by year that closely parallels the curve of Dow-Jones Averages on the New York Stock Exchange. Since the donors considered are distinctly not in the investment class,

it would appear that the psychology of human giving reflects very closely general economic trends. This is a further argument for the psychological basis of financial cycles.

In the light of such relevant facts as have been presented thus far, we may summarize as a workable brief the following:

1. Business fluctuates up and down in more or less regular cycles of about a decade.
2. Sunspots fluctuate in numbers and in intensity in more or less regular cycles of a little over a decade's duration.
3. With the variation in sunspots, the sun is known to vary the quantity and quality of its radiation sent to the earth.
4. Variation in radiation, particularly in the ultraviolet, is known to be capable of profound biological and physiological changes.
5. Demonstrable variations in the ultraviolet light of the sun are known to be accompanied by changes in the state of the earth's atmosphere.
6. Changes in the atmosphere and the electrical ions have been found by some scientific workers to be accompanied by biological and physiological changes.
7. Certain plants have been found to increase their vitamin content when irradiated with ultraviolet light.
8. Vitamins and ultraviolet radiation have come to play an important part in physiological functioning, particularly as regards the endocrine glands.

9. Moods of human temperament are closely associated with the secretion of the endocrines.

10. Buying and selling waves with corresponding fluctuations in commodity prices will, in the long run, reflect confidence or anxiety on the part of the buying public.

11. The stock market is the direct evidence of the integrated psychology of the investment public.

12. The composite curve of business activity, therefore, is fundamentally a curve of mass psychology.

13. Variations in the quantity and quality of sunshine may be indirectly but nevertheless definitely associated with moods of optimism and pessimism.

14. Sunspots as indices of the activity and the character of solar radiation may therefore be expected to be accompanied sooner or later by cyclical changes in optimism and pessimism of the masses.

The preceding fourteen points may be regarded as fundamental facts and assumptions in a document supporting the hypothesis that sunspots affect business.

Definite investigations should ultimately make it possible to substantiate or amend these statements. Some of these will doubtless be amended. I cannot but believe that accumulating evidence will show many of them valid. Ratification rests in the hands of science.

CHAPTER VI

Measuring Sunlight

Have you ever taken ultraviolet light treatments systematically? If so, you have probably noticed how carefully the dose was measured. Carelessness in exposure to ultraviolet may have painfully reminded you of the importance of this when you have thoughtlessly prolonged sunbathing. One has to be particularly careful at the beginning of the season until the skin has developed its protective coating of tan. The sensitive cells may be easily injured by overexposure.

For measuring the proper dosage of these health-giving rays, a new instrument has recently been developed. Quite appropriately it is called a dosimeter, for its purpose is to measure the proper dose so that the exposure may be suited to the individual. The dosimeter is coming into general use in clinics which specialize in ultraviolet treatments. It will interest you to know that one of these instruments is now in actual use at the Blue Hill Observatory at Hyde Park, Massachusetts, for measuring the daily values of the ultraviolet light from the sun.

It is obvious that if we are going to make systematic studies of the intensities of sunlight to find out whether

or not the ultraviolet rays from the sun are more intense during the summers when sunspots are numerous than they are during the years when sunspots are less frequent, we need some sort of instrument similar to the dosimeter for the purpose. The agility with which one's skin is burned or tanned is hardly a sufficiently exact scientific measurement. Then, of course, the effect would vary greatly with the individual.

We have said enough about the effect of ultraviolet rays from the sun on human behavior to understand the desirability of quantitative measurements of them. So I am going to tell you something of the way in which scientists accurately measure solar radiation.

Before telling you of the delicate instruments they have devised, however, let us reflect a bit upon the nature of the radiation which comes from the sun. While physicists are still debating technical theories that will completely and satisfactorily explain to them the exact mechanism by which the heat and light from the sun come to the earth, we shall not be very far wrong if we picture the sun's rays as a series of waves or vibrations set up by the sun which come unhindered through space and are absorbed by the earth, growing things, our bodies, or anything else they strike. Of course the sun plays the big part. It is the source from which all these vibrations start. You see, the sun is in a sense a big and powerful broadcasting station, and the waves or pulses of radiation which it sends us are not very different in kind from

the electric waves sent out from broadcasting stations. There is one vast difference, however. The waves of light and heat emitted from the sun are very tiny little things. They are only 1/50,000 inch long, and they vibrate very, very rapidly compared to the radio waves on which our favorite musical program may be broadcast. In the terminology of radio, we should say they are like waves of very high frequency. Now, to tell something about the length and the frequencies of the different kinds of waves in the sun's radiation, we need some kind of contrivance that will show to our eyes the effect of the different frequencies in sunlight.

Everyone is familiar with the scintillating rainbows that may be made to dance about the walls or the ceiling of the room through the movement of a piece of cut glass standing in the sunlight. Everyone of these little rainbows is a result of the glass that bends the sunlight falling upon it in a way which depends upon the number of vibrations per second in the tiny little waves of light which strike it. The waves that are vibrating fastest come off from the cut glass as blue light. Those which are just a little slower in their vibrations come through as green and yellow light, while the slowest ones that we can see are from the red end of the little colored band that shines so prettily before us.

Each one of these little rainbow-colored patches constitutes a spectrum of the sun. This colored band

of light is doing its best to analyze the sunshine for us; and every one of the colors extending from the red through the orange, yellow, green, blue, and violet has a wealth of meaning. Any device which will show us a spectrum of this sort is a spectroscope. In a sense, then, the cut-glass object, however useful or ornamental, is a bit of a scientific instrument—a spectroscope. If we utilize this principle to construct an instrument especially for analyzing sunlight in this way, we would do it a little differently.

In a real scientific spectroscope a carefully made prism of glass takes the place of the cut-glass object in our illustration. There are usually various lenses employed to increase the intensity of the light and magnify it. These are mere matters of detail. The important result is that when sunlight passes through the instrument, a single colored band is to be seen stretching over a considerable area. This we may examine and measure as we please. We should think of each of the colors represented and every gradation of the colors as a result of the different frequencies with which vibrating atoms on the sun send out radiation.

Let me tell you something about how rapidly these little waves vibrate that produce the different colors of the spectrum. Everyone is more or less familiar with cycles of vibration. The pendulum in the clock vibrates to and fro. Each time it goes over and back it has completed what we call one cycle. Electricity in the wires which lights the lamps in your house, heats your

flatiron, or runs the refrigerator or the vacuum cleaner consists of vibrating pulses. The filament in your desk lamp is heated by these electrical pulses that vibrate in most community lighting systems at the standardized rate of 60 cycles per second. This is so rapid that the hot filament in the electric bulb does not have time to cool off before it is heated again, so that it sheds a continuous, uniform light. In a few places where you may have been, you have been able to detect a slight flickering in the light from electric lamps. This is because some commercial circuits operate at lower frequencies. If it is as low as 30 cycles per second, you may perceive a slight but rapid change in the brightness of the electric lamp as the filament starts to cool off a bit during the thirtieth of a second in which the electric pulses come and go.

When you listen to your favorite program over the radio, the radio waves coming from the broadcasting station are vibrating somewhere from 550,000 to 1,500,000 times per second as they enter through the antennas of your radio. When you set your dial, for example, to receive the program from WBBM, Chicago, you make the setting 770 kilocycles as listed in the radio page of your daily paper. This means that the vibration of the electric waves coming through the air from Chicago number 770 thousand per second, for a kilocycle is literally 1000 cycles.

Now, when we look at the solar spectrum, the red light on one end of the colored band is the sensation

we get when our eyes receive 400 million million cycles in a second. As we look toward the green and blue of the spectrum the frequency in these electrical waves of sunlight increases constantly until we reach the deep violet hue at the extreme end of visibility. Here the frequency or the number of vibrations per second of the light waves is 800 million million cycles per second, or just about double that of red light.

There are still light waves of higher frequency out beyond the violet end of the spectrum which we cannot see but which will affect photographic plates very strongly. These are the ones that will give us sunburn, even though we cannot see them. This is the region that we call the ultraviolet. It is called *ultra*violet because it is literally beyond the violet, the deep orchid color which is made up of the fastest vibrations to which the optic nerves of our eyes will respond. Right in this region, then, is all this ultraviolet radiation that we have been talking about that affects plant growth, that gives us sun tan, that will prostrate us if we receive too much of it, that electrifies the earth's atmosphere 100 miles up, making possible all our radio communication.

It is rather exciting to think that this most important part of the solar spectrum and the one which produces vitamins in plants and animals is in the region of light which we cannot see at all. Perhaps we should call it dark light. Dark light would be rather too loose a term to apply to this region, however, for we have

another region of dark light down at the red end of the spectrum. Out beyond the red there are vibrations in sunlight too slow to make any effect on our eye. Perhaps we should call this region the ultrared, but just to be different and to avoid confusion with the ultraviolet we call it the infrared region—that is, inside the red.

So there are really two kinds of dark light—the one beyond the violet, and the other inside the red. The relatively slower vibrations of the dark light inside the red we feel as heat. So you see it does produce a sensation in our nervous system even though it does not affect the eye. Isn't it curious to think that the eye, which is so sensitive an optical instrument that it can see very faint stars at night, completely falls down in detecting radiation which happens to be a little slower than 400 million million vibrations per second on the one hand or a bit faster than 800 million million cycles per second on the other hand? Yet our skin, so to speak, picks up these waves where the eye leaves off. The fact that we sunburn shows us that our skin also responds to the other kind of dark light, the ultraviolet radiation.

Our eyes cannot see heat, but we feel the warmth from the sun or the heat from the radiator. This is due to the fact that the slow vibrations in the infrared are felt by the skin and transmitted to our nerves. While the eye is a truly beautiful instrument, it is really very limited in its range. The range of the eye, to use a

musical analogy, is only one octave. Were we dependent alone upon our eyesight for analyzing radiation from the sun, we should never know that the sun brought music of more than one octave. Fortunately, very sensitive devices can be made which will detect the energy that is vibrating either too slowly or too rapidly to be seen by the eye.

One of these devices is the photographic plate which picks up the higher frequencies, and the other is some form of a heat-measuring instrument which will pick up the slower vibrations inside the red end of the spectrum. Fortunately, too, the photographic plate may be made fairly sensitive to the whole visible region of the spectrum and also for a considerable distance into the infrared. When we use a photographic plate in connection with the spectroscope, we can get a map of the effects of the radiation from the sun over a very large range of frequencies all at one time. Of course the photographic plate does not show us the beautiful rainbow colors of the spectrum, but the photographic emulsion on the plate darkens wherever the vibrating radiation from the sun strikes it. The more intense radiation blackens the plate more heavily; less intense radiation blackens it but slightly. With a spectroscope and the photographic plate we can learn very much about the quality and the intensity of the sunlight in which we live and move and bask.

In a professional spectroscope, the sunlight falling upon it is intercepted by a very narrow slit which

forms a part of the optical system of the spectroscope. This slitlike window restricts to a hairline the illumination falling on the spectroscope. When we look at the resulting spectrum of sunlight or photograph it, it is found that the banded spectrum is no longer a continuous blending of colors from red to violet. There are numerous little vacancies where the colored band is interrupted. These gaps give the impression of dark spaces or pencil lines crossing the colored band vertically.

From a long study of the kinds of light given out by the various chemical elements, we have learned how to interpret the meaning of these lines in the spectrum. We see that they are arranged in definite patterns, and we have come to know that they represent certain missing frequencies in the scale of waves which come to us from the sun. Either these were frequencies which were never sent out from the sun's broadcasting station, or else they are frequencies that have been absorbed on the way.

Years of study and analysis of the spectrum tell us that what has happened is that the light from the brilliant surface of the sun had to pass through layers of various cooler gases on the way. These gases or vapors are really the outer part of the sun, and the sunlight passing through clouds of hydrogen, sodium, calcium, and many other elements has had to pay each of the little atoms of these elements an export tax to get out. Each particular element imposes its protective

tariff on the particular kind of vibration which its own radiating machinery might have manufactured. Those who have worked with spectroscopes, therefore, have learned to recognize these gaps or dark lines in the spectrum of the sun and to decode them. They represent the absorbing powers of various elements in the sun's atmosphere and portray unmistakably the various chemical elements which came in for their share in the wealth of radiation of sunshine, before they would allow it to pass earthward.

With the radiation of the sun sorted out in this fashion it becomes easier to study the quality of sunshine and any change in the intensity of it which may affect things on the earth.

In 1924, near the beginning of the last sunspot cycle which came to an end in 1933, one of America's foremost astronomers began systematic measurements of the ultraviolet light in the solar spectrum so that science might ultimately be able to answer the question as to whether the intensity of ultraviolet sunshine really did change from year to year and how much the variation in its intensity might really be. This astronomer was Dr. Edison Pettit of the Mount Wilson Observatory of the Carnegie Institution. Dr. Pettit had been working for years to develop a simple but very sensitive mechanism which would measure this energy. Knowing that the vibrations of sunlight, no matter what their wave length or frequency might be, have a certain amount of energy in them which turns

into heat when they strike an absorbing surface, he determined to utilize this heat coming in the ultra-violet rays to generate electricity. Then with a suitable measuring instrument for the electric current resulting, he could tell just how intense was the ultraviolet light which he was measuring.

Did you know that the warmth of your fingers could be made to generate an electric current? Take a piece of copper wire and a similar piece of iron wire. Twist this pair of wires together at each end. If you hold one of the junctions between your fingers which are at blood temperature and leave the other junction exposed so that it will be no warmer than the temperature of the room, an electrical current will flow through the little loop you have created, due to the fact that one end of this pair of wires is warmed by your fingers over and above the temperature of the other end. If you were to connect a sensitive electric meter into the circuit, you would see the current flowing in the wire, and you could measure its strength by the reading of the meter. Any two pieces of wire of unlike material will do the trick, but some combinations are much more effective than others.

Dr. Pettit knew this, so he took a piece of bismuth wire and silver wire and joined the ends. To make the affair sensitive, he used tiny little bits of wire which would respond very quickly to changes in temperature of even a few thousandths of a degree. With a very sensitive meter connected into the circuit, he could

measure the actual difference in temperature between the junction which he exposed to sunlight and the one end which was left shielded from the sun's radiation.

It was then only necessary to devise some screen or filter which would cut out all of the sunshine except the ultraviolet light. What do you suppose he selected for this filter? A solid sheet of silver! Probably it never occurred to you that silver would let light shine through it. If the silver sheet is thin enough, however, ultraviolet light will go through, whereas ordinary light will not be transmitted at all. The sheet of silver which Dr. Pettit used was only about one-millionth of an inch in thickness. Yet this thin film of silver for transmitting ultraviolet rays from the sun would stop all other kinds of light from getting through. So he arranged his little thermoelectric battery, or thermocouple as he called it, so that when the sun shone the ultraviolet light would be transmitted by the silver screen to his recorder. The meter which he used to record the amount of electricity generated would thus give the measure of the intensity of the ultraviolet light shining into his instrument.

Of course, some days sunshine may be brighter than on other days, owing to haze in the earth's atmosphere. So he arranged to compare the readings through the silver screen with similar readings made by sunlight shining through a very thin film of gold. He selected gold, for gold lets through only a very narrow strip of green light in the solar spectrum, a region which he

believed would vary very little compared with the variations he hoped to measure in the ultraviolet.

Every day since 1924, on the top of Mount Wilson in California, Dr. Pettit's apparatus has been measuring the strength of ultraviolet light as compared with the green light in the solar spectrum. Has he found that it varies from day to day? He certainly has. Sometimes as much as 30 per cent has been found. The ultraviolet light increased very greatly in its intensity with the rise in the numbers of sunspots from 1924 to 1927. It was also very high at the end of 1929 when sunspots were most numerous. Then as the sunspots decreased in number, the ultraviolet light began to diminish again.

As a result of Dr. Pettit's work, we feel that there is now a scientific basis for believing that the ultraviolet radiation from the sun is, in general, stronger during the years around sunspot maxima than during the years around sunspot minima. There have been some discrepancies in the measured results. During the middle of sunspot maximum in 1928, the ultraviolet light for some unaccountable reason fell off to nearly as low a value as it had in 1924 when he began his observations. This does not necessarily mean, however, that the actual strength of the ultraviolet rays sent out by the sun was less at this time, for it may very well be that many of these short light waves were absorbed at that time in the upper atmosphere of the earth and thus did not get through to the top of

Mount Wilson where the measuring apparatus was stationed.

Up above the stratosphere, there is a thick layer of ozone which scientists believe is produced by the ultraviolet light of the sun shining on the oxygen molecules of the air. As the ultraviolet light from the sun increases, more and more ozone will be formed. Now, when this oxygen goes to form ozone, it is at the expense of ultraviolet radiation. Thus the amount of ultraviolet light from the sun used up in making ozone will never reach the earth's surface at all. Moreover, the thicker the ozone layer the more ultraviolet radiation is absorbed in it. So you see that during 1928 when the sunspots were most numerous, the intensity of the ultraviolet rays from the sun may have been so great as to create a very thick layer of ozone in the upper atmosphere, which in turn would cut off from the earth's surface a great deal of this ultraviolet radiation that was actually responsible for the increased ozone. This may be the explanation as to why there was a drop in the amount of ultraviolet radiation measured by Dr. Pettit's apparatus just at the time of sunspot maximum, when we might have expected the greatest amount to be recorded.

When the sunspots subside, it seems quite likely that the sun sends us less ultraviolet light so that the rate of production of ozone in the upper atmosphere of the earth will, in general, follow with a decline in the sunspot curve. If the ozone layer, however, thins

very much, it will be less efficient in screening the ultraviolet rays from the surface of the earth. So we momentarily find in Dr. Pettit's measures that there will be times when the ultraviolet light seems to grow stronger at sunspot minimum, for ozone rapidly decomposes unless the supply of ultraviolet rays from the sun is kept up.

We see, then, that there may be many variations in the results of Dr. Pettit's investigations and that one cannot expect too close a correspondence between sunspots and ultraviolet light. One thing, however, is certain, and that is that measures being made at Mount Wilson give an exact indication of the ultraviolet sunshine that comes through the atmosphere to the surface of the earth. After all, it is the quality of the sunlight that reaches the earth's surface that is important to growing things.

Owing to the important bearing ultraviolet sunshine has upon human health, the Desert Laboratory near Tucson, Arizona, set up one of Dr. Pettit's instruments. It would appear very desirable that additional apparatus of this sort should accumulate records in other parts of the world as well, for it is quite likely that the atmosphere of the tropics as compared with the atmosphere in the temperate zones behaves differently in screening ultraviolet light out of sunshine.

Another man who has long been interested in measuring sunshine because he believes this to be important

to mankind is Dr. Charles G. Abbot, secretary of the Smithsonian Institution in Washington.

In his early days Dr. Abbot was intimately associated with Samuel Pierpont Langley, a predecessor as secretary of the Smithsonian Institution. Langley was a great student of the sun. With a sensitive electrical instrument he was one of the first to explore the energy throughout the whole solar spectrum. He believed that the amount of heat and light the sun sent to us was not constant but varied from year to year and perhaps even from day to day. Langley thought that if one were to measure the total amount of heat and light from the sun systematically, year in and year out, one would find not only that the amount of radiation from the sun varied but that this variation in heat from the sun would prove to be a very important factor in forecasting the weather weeks and even months ahead. It was therefore natural that Dr. Abbot should carry on the project visualized by Professor Langley.

For forty years now Dr. Abbot has been measuring the change in total energy that comes from the sun and daily exploring the solar spectrum. He developed a special instrument which would convert all of the energy in sunshine into heat. He calls his contrivance a pyrheliometer, which literally means a meter for measuring the heat of the sun.

This device consists essentially of a small circular box closed on all sides and having a blackened silver

disk for a top cover that may be exposed directly to the sun's rays. The little circular box is filled with water into which is inserted the bulb of a thermometer with the stem extending outward. This simple little affair is mounted in a convenient way mechanically, so that it can be turned readily to allow the sun's rays to fall perpendicularly on the surface of the box. There is a shutter something like a camera shutter which may be opened or closed to admit the sunshine to the water cell.

Every day this instrument is carefully pointed at the sun, the shutter is opened, and sunshine is allowed to fall on the container for one minute. Sunshine striking the blackened silver disk is turned into heat which warms the water within. The thermometer records the rise in temperature of the known amount of water as it is warmed during the minute in which the sun's heat is allowed to fall upon the instrument. From the rise in temperature of the water, the total amount of energy in the sunshine can be readily calculated.

It is found that the average amount of radiation from the sun is 1.94 calories per square centimeter per minute. The calorie is a unit of heat familiar to all engineers and is the amount which is necessary to raise the temperature of one gram of water 1°C. in a minute of time. This value which Dr. Abbot has obtained as a measure of the heat of the sun is often called the "solar constant." It was originally thought that the amount of heat from the sun was indeed

constant, but Dr. Abbot's measures have shown that it varies sometimes as much as 4 per cent. From the laws of the variation of the sun's radiation, he believes it will be possible to predict weather far in advance.

Certainly the heat from the sun is a very important factor in the affairs of this world. Every square yard of the earth's surface exposed to sunshine is constantly receiving the equivalent of one and one-half horsepower of energy. Sometime when fuels are more expensive than they are today, we may be utilizing the sun's heat directly, running all sorts of machinery. In fact, this idea is quite a hobby with Dr. Abbot. He has recently had on exhibition a solar engine which he has invented. By means of this he can transform sunshine into mechanical power that may be turned to any useful purpose.

Dr. Abbot's chief concern, however, is to learn how to forecast the weather from the changing values of the solar constant which is being measured every day at three different stations maintained by the Smithsonian Institution. This persistent scientist has traveled the earth seeking ideal locations for his solar observing stations. To be of greatest value to mankind, observations must be made every day in the year. That necessitates seeking places where sunshine is as continuous as possible. Furthermore, no end of trouble is caused by moisture in the earth's atmosphere that absorbs some of the sun's heat. To reduce these difficulties to a minimum, he has, therefore, sought to find places as free from water as possible. His

observing sites are in high, desolate, arid regions. One of these is at Table Mountain in California. Another is at Mount Montezuma, Chile; and the third is on Mount Sainte Catherine in Egypt. He has endeavored to select stations widely separated and in typical regions of the globe, so that he could compare the measurements of solar energy from very independent observations.

In addition to the readings made with the pyrheliometer, an observer laboriously explores the energy through the whole solar spectrum, at each of these stations, in order to find how much absorption should be allowed for in correcting for the effect of the earth's atmosphere through which sunshine is transmitted.

Dr. Abbot's most recent plan is to send up his apparatus into the stratosphere, suspended from balloons. With 95 per cent of the earth's atmosphere below the apparatus, he would then be able to get better measures of ultraviolet light than can be done at any station on the earth's surface. If funds could be found for such a venture, he believes that an even closer relationship between the sun and the weather would be found than has yet been discovered.

Since life on earth is so dependent upon sunshine, its amount and quality, we see how important it is that careful measurements of sunlight shall be made continuously day in and day out, year after year. It is only when we have scientific records of this nature that we can hope to discover the answer to many of the questions about which we have speculated.

CHAPTER VII

Weather and Sunspots

THE trite remark, often attributed to Mark Twain, that the "weather is something that everybody talks about, and nobody does anything about" is perhaps less pertinent today than ever. More and more people are becoming concerned with the weather and its prediction. The impetus given to investigations in meteorology by the exacting demands of air navigation bids fair to have opened a new era in meteorology. Weather stations at every airport not only demand trained meteorologists but demand of them powers for predicting weather for which the world finds itself suddenly unprepared.

The conventional weather forecasting of yesterday which has depended largely upon telegraphic communications from the Western states is not satisfying the need of today. Even well-developed storms in the Far West cannot always be counted upon to pursue their prescribed paths. Science is seeking new information as to the developments and movements of storm areas. For this reason the last few years have seen the initiation of daily airplane flights into the upper

atmosphere to find out the actual conditions off the earth, for a storm area after all is a three-dimensional thing.

Old timers on Beacon Hill in Boston have made repeated complaints that the whirring of the early-morning weather plane disturbed their slumbers. But times have changed since Beacon Hill was first graced by the elite of New England, and airplanes must continue to go aloft for observations in the upper air if the interests of air transportation and agricultural progress are to be fostered by up-to-date meterology. Daily observations obtained aloft are now routine necessities for the weatherman.

Fortunately, miniature weather stations equipped with radio, not much larger than a good-sized match box, are being developed that can be sent ten miles up by balloons. All the while these little automatic weather stations are aloft, they will broadcast to the observatories below barometer readings, temperatures, and humidities, while they are pursuing their solitary flights. Even if the balloon and apparatus are blown to sea, it will be no great loss. The cost will be less than a single day's observation by plane.

These instruments, called meteorographs, have already made several successful experimental flights from the Blue Hill Observatory and elsewhere.

When they go into routine service, the light sleepers on Beacon Hill may continue to dream while meteorographs silently steal away into the upper atmosphere,

bidding top-o'-the-morning to the early-rising pigeons astride the gilded dome of the State House.

The Weather Bureau for several years has tried to meet the demand for forecasting weather more than a day in advance and now attempts forecasts for a weekly period at a time. Business and transportation lines, however, would like to know not a week but months and often a year in advance, so that they may judge their demands accordingly. While the United States government has placed the Weather Bureau on a sound basis and is arranging its program according to the latest developments in meteorological thinking, the Department of Agriculture has been appropriating thousands of dollars during the last few years to investigating the possibilities of long-range weather forecasting along many nonconventional lines. Aside from government agencies, various individuals from time to time have established private forecasting services based on conceptions which are not ordinarily recognized as conventional, but which, according to their own enthusiasm, have proved at least as accurate in predicting weather at long range.

The idea that weather may be associated with sunspots is not in itself new. Many investigators have attempted to find relationships between sunspots and weather changes with the ultimate hope that since we can predict with reasonable accuracy the main trends in the solar cycle, we shall be able to predict likewise the main trends in the changes of weather

Evidently the relationship between weather and sunspots is not a simple one, or the secret would have been found before now.

In spite of many conflicting results, it appears that in general the temperature of the world at large is somewhat higher at sunspot minimum than at sunspot maximum. This seems at first paradoxical, since we might well expect that at sunspot maximum the sun would send us somewhat more heat and radiation than at sunspot minimum. Many of the observations of Dr. Abbot, especially during the earlier years, seem to corroborate this. It is not unthinkable, however, that the surface temperature of the globe could be actually cooler in some years even though the earth is actually receiving more heat from the sun. Increased heat may produce increased evaporation, which, in turn, will result in increased rainfall. The increased rainfall actually lowers the temperature of the earth's surface and, again by evaporation, continues to cool the air immediately above the earth's surface. Then, of course, as the air is warmed near the surface of the earth, it rises, and the cold air comes in from northern regions with its chilling effect. So it is entirely possible that even an increase in the heat received by the earth from the sun may result in increased circulation in the earth's atmosphere that, so far as surface conditions are concerned, can actually bring about lower air temperatures in selected regions than would otherwise be the case.

One certain thing is that all the weather on the earth is produced by the sun. It is the sun shining over the tropical region which heats the large masses of air in the region of the earth's equator. These masses of warm air ascend upward while the cold air from the polar regions spreads toward the equator to fill the place occupied by the ever-rising air. Because of the rotation of the earth, whirlpools and eddies are formed in these air currents which result in winds and storms that bring our variable weather. So far as changes in the sun's radiation affect the general circulation of the atmosphere, it certainly is to be expected that such changes will ultimately affect the formation of the storms and the storm tracks resulting. One of the difficulties in establishing any intimate connection between weather and sunspots is that our observations of weather have to be very local.

If one averages the weather conditions over the entire globe, as, for example, comparing the average rainfall recorded at observing stations throughout the world, one might at first thought expect to find some relation with sunspots, assuming that sunspots have anything to do with weather phenomena. Such, however, is far from the case. A storm in one region of the globe means clear weather elsewhere, and a region of excessive rainfall in a given year will usually be offset by one of extreme dryness occurring somewhere else. To average together such effects leads to no definite conclusion. Furthermore, since storms travel over more

or less defined tracks, the very migration of these storm centers makes it quite impossible to get significant results from hundreds of stations scattered from the polar regions to the equator. Yet if progress is to be made, it will come through a consideration of the distribution of weather as a whole over the entire globe. With a more accurate picture of world weather, indications for weather in a restricted locality for any given time may be more easily understood.

One of the most interesting personalities who has spent a lifetime in the investigation of world weather and its possible relation to the sun is Mr. H. Helm Clayton of Canton, Massachusetts. Mr. Clayton is a well-known scientist who has spent many long years in the Weather Bureau service and has been remarkably successful in his long-range forecasting. While Mr. Clayton takes cognizance of all the usual meteorological data employed by the government officials, he has utilized his long years of fundamental study of world weather in analyzing certain well-defined cycles which his keen perception has noted as fundamental in the recurrence of storms, rainfall, clear weather, and cold waves.

Mr. Clayton is a firm believer that changes in the sun are accompanied by fundamental changes in the earth's atmosphere and has found certain definite indications that changes in the earth's atmosphere in different parts of the world accompany the appearance and disappearance of sunspots throughout the eleven-

year cycle. He has not only shown certain definite relations between temperatures and sunspots over definite areas of the globe, but he has shown why many investigators have failed to find such a relationship.

Looking at the weather on a world-wide scale, Clayton has not only found that pressures seesaw from one region to another, but he has noted that the way in which they seesaw depends upon sunspots. He finds that there is an opposite trend over the continents and oceans in summer as compared with winter and that the trend is different in the equatorial regions from what it is in extratropical belts. In the equatorial region the temperatures are distinctly lower at sunspot maximum and higher at sunspot minimum. The same is true in the north and south temperate zones, but in the arid subtropical regions the temperature actually averages a little higher around a sunspot maximum than around a sunspot minimum.

Mr. Clayton has examined the snowfall records at the Blue Hill Observatory in Massachusetts and finds 40 per cent more snow at sunspot maxima than at sunspot minima. He has traced the ice records in the Arctic and Antarctic and finds two to three times as many icebergs at sunspot maximum as compared with sunspot minimum. This corroborates the findings of other investigators who have come to the conclusion that temperatures, at least in the temperate zones, are colder when sunspots are most numerous.

From a careful study of precipitation records selected over the whole globe, he has mapped the world into regions which show greater rainfall when sunspots are most numerous and regions where rainfall is actually deficient at sunspot maxima. While the North Atlantic shows 10 to 20 per cent more precipitation in years of greater sunspots, the eastern half of the United States is in the region where the rainfall is actually less during maximum activity on the sun.

South America, Africa, India, and Australia all show again 10 to 20 per cent more rainfall during sunspot maxima than during sunspot minima. From a survey of world weather he has drawn the conclusion that at sunspot maximum the atmospheric pressure is less at the equator than it is during the years when sunspots are infrequent. But this area of lessened atmospheric pressure at the equator is compensated by a zone of greater pressure at sunspot maximum than at sunspot minimum in the northern hemispheres. Any wholesale change in the distribution of atmospheric pressure or barometer readings over the globe which follows the sunspot cycle must ultimately affect the number, intensity, and nature of the storm tracks over the United States or other typical regions of the globe.

This has led Professor Kullmer of Syracuse University to investigate the tracks of storms over the United States during the years when sunspots were in evidence as compared to the years when sunspots were lacking. On the basis of five solar cycles he has

found that there appears to be a shift in the storm tracks of the United States which corresponds very much to the shift in the location of sunspots on the surface of the sun. Furthermore, examining years of solar and meteorological data, he has found on the average 40 per cent more storms passing over the fundamental storm track of North America during sunspot maxima than passed over this same region during years of sunspot minima. He based his studies on records extending from 1883 to 1913.

Many investigations have been made of the relationship between sunspots and tropical hurricanes on the earth. R. Wolf, who was one of the earliest investigators of sunspots, has shown that during years of maximum sunspots, there have been on the average six to eight violent hurricanes per year, while the average during sunspot minimum is only one or two per year. More than three times as many hurricanes have visited the Bay of Bengal in the Arabian Sea during the years of sunspots. The South Indian Ocean in the same period showed an increase of 65 per cent in the numbers of such hurricanes. Reverse conditions, however, were indicated for the South Pacific Ocean, where the number of tropical hurricanes was twice as many during the years of few sunspots as during the years of many sunspots. Other investigations have indicated that as the sunspot cycle progresses, the longitude of the West Indian hurricanes has drifted from 59° west to that of 88° west.

All of this shows that weather is a highly complex phenomenon which depends upon turbulent air currents traveling in different directions, influenced by continents and oceans, equatorial heat, and the arctic cold. To upset the balance of one of these regions may change the character and sequence of any of these phenomena in any of the other regions.

Mr. Clayton concludes that all our weather is the result of progressive wavelike movements of certain disturbed areas originating in different parts of the world. He finds that during each cycle of change in solar activity, the centers of high barometric pressure move from high latitudes to low latitudes and back again. The speed with which these waves progress appears to be inversely proportional to the length of the period of oscillation.

This meteorologist finds much in common in the behavior of the weather in widely separated parts of the earth, as, for example, in the central United States and Australia. Changes in rainfall in central North America show a striking similarity to changes in precipitation in central South America. Changes in the barometer in San Diego act very much as they do in Buenos Aires. In this respect, Ceylon varies in an opposite manner to Santiago, Chile. This noted investigator finds there will be several years when the differences in barometric pressure between the equatorial region and the north temperate zone becomes greater than normal, and then this period will be

followed by several years when the pressure differences become less than normal. The shifting of these centers of action is found to be definitely associated with sunspots. His conclusions are based on so large an amount of data and upon such a wide experience in meteorology that no one interested in weather and weather pre-

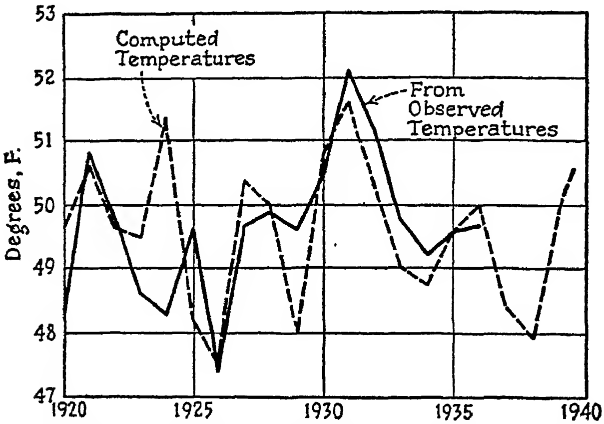


FIG. 11.—Clayton's predictions of New Haven temperature and observed values on the basis of the 68-year period in sunspots compared with values observed subsequent to prediction.

diction can overlook the important contributions which Mr. Clayton has made.

From some unpublished material which Mr. Clayton has shown me while this book was in preparation, it appears that one of the most important discoveries in the matter of weather prediction may come as a by-product of some of his recent investigations relative to the analysis of sunspot data. As will be discussed in a later chapter concerning the prediction of sunspots,

Mr. Clayton has found that the most promising period he could use in predicting sunspot numbers is that of sixty-eight years. Furthermore, one-half, one-third, one-fourth, one-fifth, one-sixth, one-seventh, and one-eighth of this interval all appear to be contributing cycles. When Mr. Clayton used these same intervals in an examination of New England temperatures and rainfall, he has found a remarkable correspondence between his predicted and observed values of temperatures at New Haven, Connecticut. The curve reproduced herewith shows how closely the actually observed data match his predictions from 1910 to 1936. Evidently New England has been getting colder since 1931 and may be expected to average temperatures below normal until about 1939.

Dr. Abbot of the Smithsonian Institution, whose painstaking work of measuring solar radiation we have already discussed, concurs with Mr. Clayton in the belief that if there were no variations in the sun's radiation, atmospheric movements would soon be reduced to a stable system with periodic exchanges of air between the equator and the pole and between the ocean and the land. Without variation in the sun, these exchanges would depend mainly upon the variation of the heat received by the earth due to day and night and to the seasons. These would be set into operation merely by the relative motions of the earth as it turns on its axis and journeys about the sun. Both Abbot and Clayton firmly believe that the existing abnormal

changes in weather which we experience have their chief source of origin in variations of the sun itself.

Dr. Abbot's long investigations of solar variations and weather at the Smithsonian Institution have convinced him that the sunspot period is an important factor in untangling the vagaries of the weather. He finds that the variations in the sun's heat and in the weather really appear to comprise twelve or more regular periods, the most conspicuous of which is a period of twenty-three years, equal to twice the average sunspot cycle. As we shall see later when we are concerned with the electrical nature of sunspots, twenty-three years really elapse between the recurrence of sunspot cycles of the same kind. The examination of weather records at strategic points, Dr. Abbot says, shows very definitely this long period of weather variation covering twenty-three years.

One puzzling difficulty in all these investigations has been that a definite relationship between sunspots and weather appears to persist for a considerable number of years; then the relationship gets out of step and changes its phase. Then, for one reason or another, over a considerable time, the weather effects will run just opposite to the expected. Now Dr. Abbot has new light on this puzzling difficulty.

In examining weather records from 1875 to 1925, he has discovered that in the eleven-month variations of temperature at a selected station the temperature rises with increasing sunspots if the numbers of sunspots

are not large. When, however, sunspots approach a maximum, the increase in temperature follows the increase in sunspots less markedly. During the years when sunspots are very large and most numerous, the temperature actually appears to fall with increasing numbers of sunspots. We might interpret this as meaning that there is a certain optimum of sunspots for normal weather conditions. If sunspots are less than this amount, we get one effect; whereas if they are more than this amount, the opposite effect results.

We might take as an example the dependence of one's working efficiency upon temperature. Let us say that your optimum working room temperature is 68° Fahrenheit. You come into the office some winter morning and find it is only 60° with the thermometer slowly climbing. As the thermometer rises, you literally warm up to your work and perform it more efficiently. If, however, through lack of proper heat control, the thermometer continues to rise to 80° and above, you begin to slow down again. If your experience with temperature and working efficiency had been limited entirely to a range between, say, 50° and 70°F., you would have derived the law that as temperature increases, your working efficiency increases. It might have been a bit of a jolt the first time you were subjected to temperatures of 80°, 90°, or above to discover that as the thermometer continued to rise, your ability to perform your duties and create new ideas actually lessened.

This may serve as an example of the relationships between sunspots and the weather. With sunspots below some critical value, temperatures on the earth seem to go up with increasing sunspots. With sunspots above this critical and optimum level, temperatures on the earth react the opposite, very much as your mental efficiency runs opposite to the thermometer in the illustration we have used.

We have another example of this sort of change in our records of radio reception. A certain degree of activity on the sun seems necessary for maintaining the ionized layer of the atmosphere at the best level for obtaining reception between Chicago and Boston. With a decrease in the ionization, we may get poorer reception because the reflecting ceiling is then too high. Or, again, with an increase in the ionization of the air beyond the critical point, radio reception again becomes impaired because the reflecting ceiling is too low for best reception. On either side of the critical height of the ionized layer, therefore, changes in sunspots may produce the opposite effect, for it appears that the degree of ionization very definitely changes with solar activity.

Dr. Abbot has traced this twenty-three-year variation in the weather with many of the minor fluctuations which occur at greater and lesser intervals in the tree-ring data studied by Dr. Douglass, in the flow of the Nile River, the level of the Great Lakes, the rainfall

in Southern New England, and even in the abundance of cod and mackerel.

Another independent record of the twenty-three-year cycle is evident, according to Dr. Abbot, from the records of varves, those curious laminated markings on sedimentary deposits that may be traced through geologic time. The annual character of the layers of these claylike deposits aroused Professor Douglass' interest in analyzing the spacings. So he studied their records very much as he analyzed the rings in the trees of the forests of the Southwest. Professor Douglass finds a very prominent cycle in varves of 11.4 years, which is practically the sunspot cycle. Of course, two of these so-called Hellman cycles are the equivalent of Dr. Abbot's twenty-three-year period. Various other cycles have been traced in sedimentary deposits extending back over 1400 years.

It is the twenty-three-year period which Dr. Abbot believes is particularly important in weather and climate forecasts. He finds departures in both temperature and rainfall which have repeated themselves remarkably in these intervals. Dr. Abbot says the United States is now nearing the close of a period of considerable drought which, according to his best estimate, will not return until the year 1975. He bases his prediction on twice the solar cycle in records of both solar activity and weather. He finds this double period particularly important to precipitation.

Both the twenty-three-year and the forty-six-year cycles are traced in temperature departures from normal, not only in the United States but in Western Europe, Southern Africa, and Australia. On the basis of the past, he has at several times made forecasts which subsequent experience has shown to be remarkably well verified. If more observing stations could be established for the exact measurements of solar radiation, particularly if recorders could be sent into the stratosphere regularly every day by means of balloons, in accordance with his suggestion, it appears that so much more satisfactory observations of solar radiation would be obtained as to advance materially the whole subject of long-range weather prediction.

However complex and conflicting the results of various investigators who have attempted to link weather with sunspots, it appears that enough evidence has been presented so that one may feel fairly confident that future investigation will bring to light more and more support for the hypothesis of a connection between the weather and the sun.

We may hope for the justification of the statement made forty years ago by the pioneer investigator of the sun, Professor Langley, in his report of the Mount Whitney expedition:

"If the observation of the amount of heat the sun sends the earth is among the most important and difficult in astronomical physics, it may also be termed the fundamental problem of meteorology, nearly all whose

phenomena would become predictable if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how through the aid of the atmosphere it maintains the surface temperature of this planet; and how in diminished quantity and altered kind it is finally returned to outer space."

CHAPTER VIII

Solar Utilities, Power and Light

HAVE you ever thought how much rain falls over the entire world in a year? I have just been looking up reliable figures and find that the average rainfall for the whole earth is thirty-two inches per annum. If this amount fell at one time, it would flood the entire globe with a sheet of water nearly three feet deep. The weight of this amount of water is 480 million million tons.

All of this must have originally evaporated from lakes, rivers, and oceans, have been lifted to a cloud height of some 4000 feet, and dropped again as rain. To carry on this gigantic irrigation enterprise requires the expenditure of 220 million horsepower continuously throughout the year. So far as we know, this irrigation system has been at work for the benefit of mankind thousands and millions of years. Where is the pumping station with a capacity sufficient to carry this on year after year? The answer is, of course, the sun; yet only a very small amount of solar energy reaching the earth is consumed in running this rain-making machinery.

The greater part of the solar radiation is used in heating and lighting the earth. The sun is the greatest

utility company by which mankind is benefited. Think of the light and heat that come to us every day from the sun without a thought or consideration on our part as to the source of supply.

Have you ever stopped to consider what it would cost to light the world with sunshine if we had to pay for it? It has been remarked that every square yard of the earth's surface directly exposed to the sun receives on the average one and one-half horsepower. We pay our electric light bills in terms of kilowatt-hours. If we think of the sunshine as a public utility, we might say that every square yard on which the sun shines is receiving from the Solar Power Company one and one-eighth kilowatts continuously.

Suppose we had to pay for the light from the sun for an average twelve-hour day of daylight. The bill for but a single day would amount to 30 million million dollars even at the very low rate of two cents per kilowatt-hour.

If the sun were to dispatch to the Federal government the light bill for the United States for one year, it would call for a budget for illumination and heat of 327 quadrillion dollars. This is a figure which reduces to relative insignificance the 35 billions that have been appropriated by the New Deal administration in the last four years. Fortunately for us, Nature provides the sun's light and heat gratis. No Congressman as yet has attached a rider to any revenue bill calling for a tax on sunshine.

Of course, such large figures as quadrillions are indeed difficult to picture. So suppose we restrict our interest for the moment to the city of New York alone. The cost of sunshine for Greater New York for just one day would amount to 100 million dollars.

Such examples give us a little idea of the enormous amount of energy coming from the sun. Yet we on the earth are tapping but a very small part of the energy generated in the Solar Powerhouse. The earth itself can consume only one-half billionth of the amount of energy being generated and radiated by the sun. You see, the sun sends out its heat and light in all directions, and for every ray which strikes this tiny earth, 93 million miles away from the sun, two billion rays of sunshine appear to be lost in space, except for the few trickles that are intercepted by the other planets.

Knowing how much of the sun's energy strikes the earth and the small proportional amount which it intercepts, one can easily calculate the total output from the solar powerhouse. It is 343,000,000,000,000,000 kilowatts. The solar dynamos are running at full tilt and at continuous service.

Where is the fuel supply that keeps this power company in operation? Life on the earth during the past, present, and future is so dependent for its well-being upon this constant amount of sunshine that we may well be interested as to how long the Solar Power Company may remain solvent and whether any shutdown is imminent while human beings continue to

inhabit this planet Earth. Meanwhile, we are impressed with the apparent waste of the sun's natural resources so far as any use to mankind is concerned. Some day undoubtedly the sun will give out, but we are quite powerless to conserve any of its enormous waste for any future needs.

Millions of years ago sunshine provided the energy for growing the vast tropical forests of the Carboniferous era. It is the carbon in those fallen tree trunks that we are mining today in the form of coal, the chief source of fuel for our own public utilities. Boilers and generators turn this coal into light and power. Thus nature has stored in those primitive forests buried underground unthinkable calories of canned sunshine that brightens our highways and illuminates our buildings during the long nights when the sun is below the horizon. So the sunshine of the past is being brought literally to light again. The ultraviolet light of our health lamps fed by electric current is again directly traceable to the sunshine of those days when the dinosaurs roamed through vast tropical forests, millions of years before they began advertising Sinclair oils.

If we live where we obtain our electric current from utility companies operating solely by waterpower, we do not dodge the issue of our debt to the Solar Power Company. It is the radiation from the sun that transforms the water of the ocean, lakes, and streams into the ascending water vapor that condenses into clouds and falls in rain, feeding mountain streams, rivers, and

the rushing torrents that turn the giant turbines of the hydroelectric power plants. All power companies are but subsidiaries of the Solar Power Company. If they use coal or oil for fuel, they are drawing from the capital of sunshine stored in hidden vaults during the Carboniferous era. If they are hydroelectric plants, they are utilizing the sunshine of today and turning it into electricity. For millions of years the parent company has been supplying the earth with its energy to the extent of 230 million million horsepower. At the quoted price of two cents per kilowatt hour, the total indebtedness of the earth to the sun since the dawn of civilization has amounted to $110,000,000,000,000,000,000. How fortunate we do not have to create bond issues for taking care of the accumulated deficit.

How long the Solar Power Company can continue to operate depends upon its source of supply, and to answer this question we must avail ourselves of the best guesses of science.

There have been many hypotheses to account for the maintenance of the sun's radiation. One thing is certain. The sun is not a burning furnace where combustion takes place. Strange as it may seem, the sun is too hot to burn. Burning is an oxidation process. The temperature of the sun, with the possible exception of the interior of sunspots, is far too hot to allow oxygen to combine with any other element. In sunspots, where the temperature is somewhat lower than the rest of

the sun's surface, there is indication that oxygen does combine with some other elements. Were the sun composed of the hardest anthracite coal, and were its temperature such that it could burn under ideal conditions, calculations show that it could not have kept up its present output of light and heat for more than 1500 years. Life could have scarcely gotten started on the planet with such a paucity of fuel supply.

In any man-operated power plant the source of fuel invariably comes from the outside. Perhaps this is the reason why some scientists long held that matter must be coming into the sun from the outside to keep up its present output. The only known matter which comes to the earth from outside space consists of meteors. With this in mind, scientists once postulated that meteors falling into the sun were the chief source of its heat and light supply. Fortunately, however, this idea could be checked against experience. If meteors fall into the sun in any sufficient number to be an appreciable source of fuel, many more meteors should be striking the earth on their way to the sun than have been found to do so from observations. It has been estimated that 400 tons of meteoric matter fall on the earth in a year. But as the earth can stop only one two-billionth of such material falling into the sun, one would expect that two billion times the amount of meteoric matter falling to the earth would be plunging into the sun in a year. Even so, calculations show that the amount of energy released from this source would

be so entirely insignificant a source of fuel supply that the sun could not possibly have kept up its present rate of radiation for more than 10,000 years on any such basis.

With the failure of tangible evidence for an outside fuel supply, astronomers began to turn their thoughts to the interior of the sun as the source of its own energy. Scientists know that although the sun is largely gaseous, the material of which it is composed is continually being drawn closer and closer together, pressing inward toward the interior as the result of the sun's gravitational attraction. As far back as 1854, Helmholtz applied this idea to calculating the amount the sun would have to shrink in order to keep up its present rate of output. His calculations showed that only 200 feet of shrinkage per year were necessary. As this is too small an amount to be observed from the earth even with the most powerful telescope, one could not say whether he was right or wrong.

If, however, it is the shrinking of the sun which is responsible for its source of light and heat, one wonders how long the sun could have been shrinking at such a rate. This, too, is adaptable to calculation. It was found that at the foregoing rate of shrinkage the sun could have kept up its present rate of radiation for ten million years but hardly more than that. Meanwhile, geologists calculated from the rate of deposits of salt in the sea and the formation of sedimentary rocks in the earth that the earth must have been receiving solar energy

at the present rate for at least 100 million years. More recently, through measurements of the rate of the radioactivity taking place in the earth's crust, it has been found that the earth's age is more nearly twenty times this earlier estimate. So, however intriguing the picture of a shrinking sun supplying light and heat, the contraction theory of Helmholtz has "gone with the wind" along with the meteoric hypothesis. Neither has contributed adequately to the picture of what keeps the solar engines going.

Our best guess now is that the source of energy is within the atoms of which the sun is composed. The two simplest atoms which we know anything about are those of hydrogen and helium. Hydrogen is the high explosive gas which was the cause of the *Hindenburg* disaster, and helium is the inert nonexplosive gas which those responsible for this giant airliner would have liked to substitute for hydrogen could they have obtained it. Four hydrogen atoms constitute the necessary building material for one helium atom with just a bit of energy left over.

It appears probable that within the hot interior of the sun and stars, the transmutation of hydrogen into helium is continually taking place, thus releasing an enormous amount of heat from the surplus energy left over from each combination of four hydrogen atoms as they form one helium atom.

Here, then, is a thought for the mysterious supply of solar energy. Every time four little hydrogen atoms

make a helium atom, 1 per cent of their weight is liberated as energy. On such a hypothesis, the sun could have well kept up its present radiation from as far back in geologic time as we have any reason to consider. Of course the sun is constantly losing weight in the process. This loss of weight has been calculated to be 4,200,000 tons every second, but we scarcely need worry just yet about this fuel supply being exhausted while the sun still has 2,000,000,000,000,000,000,000,000,000 tons of matter left in it!

CHAPTER IX

Of Sunspots, the Earth's Magnetism, and Carrier Pigeons

"WHAT's all the trouble about, Susan? Why all this commotion?"

The floor clerk was speaking to the chambermaid in Room 214.

"Oh, that temperamental guest from Los Angeles insists that she can't sleep unless her bed is turned toward the north magnetic pole!"

Have you ever stopped to realize that whether you are asleep or awake, you carry on your existence on a magnetic earth?

Probably it has never occurred to you that the earth's magnetism is of any consequence except as in some mysterious way it draws the compass needle to the north. You concede that the compass proves a useful instrument for finding your way home when mountain climbing or taking long hikes over obscure and little-used trails. If you have ever been lost in the woods except for a compass, you can appreciate something of what the earth's magnetism has meant to man and his civilization as he has explored unknown regions of the globe.

Whoever first discovered the earth's magnetism is anybody's guess, but it seems probable that the idea of the compass came out of some ingenious Oriental mind and found its way to Europe during the Crusades.

That sunspots have a way of upsetting the earth's magnetism is one of the best proved arguments we have of the influence of these solar storms on affairs here on the earth. Perhaps it is far-fetched for one to base his sleeping habits on any observations as to the orientation of the bedposts with respect to the magnetic north. However, very little experimental work has been done on biological behavior as affected by magnetic forces. Now that medical science has proved that we are but bundles of nerves whose behavior patterns are determined by the flow of electrons, many new fields are open for investigation of possible effects of electromagnetic phenomena upon life and its behavior. Perhaps some persons are much more sensitive to some of these subtle forces than others.

The interesting studies that have been made at the Harvard Medical School, the Loomis Laboratory, and elsewhere which have unmistakably exhibited not only the existence of electromagnetic brain waves but a change in the pattern of these waves as the patient is subjected to external stimuli, offer a suggestion that the electromagnetic field of the earth and changes in it may have more to do with our reactions than we have ever supposed.

While I am writing this, the worst magnetic storm for 100 years has been raging for four days in the great ocean of magnetism surrounding the earth. Those who have delved into the mysteries of sunspots and magnetic changes in the earth feel well convinced that for every one of our major magnetic storms, an unusually large sunspot has appeared on the sun.

If we make a chart of magnetic changes going on in the earth for the last 100 years and compare it with a chart of the numbers of sunspots, the correspondence of the two is so remarkably the same as to convince the most skeptical as to the reality of this association.

The source and nature of the earth's magnetism is still one of the great mysteries of science. Everyone knows in a general way that the earth is a magnetic sphere. Perhaps few people realize that the compass needle does not point true north except in various restricted parts of the globe. The reason for this is that the north magnetic pole of the earth is not the top of the world but is located more than 2000 miles south of it near the Hudson Bay region. Its more exact location is latitude 70° north and longitude 97° west. Yes, there is a south magnetic pole likewise. The exact position of the south pole is less well determined, but it was very near Byrd's camp in Antarctica.

From the south pole to the north pole invisible lines of force stream over the entire globe. A compass needle points the direction of these lines of force. In the region of New York the compass actually points 10° west

of north. In nautical language this is a whole point of the compass out. If allowances were not made for this so-called variation in the compass, many a ship would be piled high and dry and fail to arrive at its destination.

Off the coast of California, the compass points east of north. At San Francisco, for example, it points 20° east of north, or nearly two points off the true meridian. When you embark on your transatlantic trip to Europe, you leave New York with the compass pointing 10° west of north. By the time you are off the Grand Banks, it is pointing nearly 30° west of north. When you dock at Bremen, it is back at 10° west again—the same as it was at New York.

To add to the complications, this variation of the compass is not the same this year as it was last year. It is constantly changing. Magnetic observations are made from time to time by the governments of the world and by scientific institutions for checking up on this temperamental field of the earth.

When the good ship *New Netherlands* sailed into the mouth of the Hudson while Manhattan was still held by the Indians, the compass was pointing north by west just as it does today. But by 1833 the compass could be relied upon to give true north to the entering ships as accurately as the polar star.

In France in 1580 the compass pointed north by east. In 1665 it was pointing true north. During the War of 1812 the needle was pointing north northeast.

The next fifty years swung it back to true north, but today at Paris it is north northeast again. Just what makes these mysterious changes in the earth's magnetism, science has not yet been able to find out.

In magnetic observatories stationed in selected regions of the globe that are remote from electric trains and power lines, it is found that the compass needle is continually wandering back and forth every day a slight amount. As the sun rises in the east, the north end of the compass turns slightly in that direction. By noon when the sun is due south, it is pointing in its normal position. Shortly after noon it begins wandering toward the west, following the sun as it goes down. By midnight when the sun is below the northern horizon, it is back to normal again. This goes on day after day, month after month; but during the years when sunspots are most numerous, the excursions of the needle will, on the average, be twice as great as they are when sunspots are lacking.

Please don't think that these daily wanderings of the needle are of a sufficient amount to lead you astray. In general, they are not sufficient to be observed by the steersman of a transatlantic liner, but they are large enough to be observed by scientists and to cause no end of speculation as to the true explanation of this phenomenon.

But we were speaking of magnetic storms. What are magnetic storms, and how are they observed? During this magnetic storm which has just been raging, we

have observed more violent excursions of the compass needle from true north than has been seen for two generations. There were times during the day when it was actually a whole degree off from its expected direction. Now, whatever has taken place in producing the disturbances in the earth's magnetism, we find not only that compass needles are upset under such circumstances but also that telegraph lines are momentarily put out of commission, that transatlantic cable communication is wrecked, and that radio communication becomes nearly impossible. Heavy electric currents surge back and forth in the earth, and overhead wires often do damage to the communication equipment.

Very delicate balances have been devised for measuring the strength of the force which pulls the compass needle north. With such devices the actual magnetic force is measured continually every day all over the world. During the years when sunspots are most numerous, we find that, on the average, the force is twice as great as during the years when sunspots are missing.

With 100 years of magnetic records to our credit, we come to the conclusion that the correspondence between changes in the magnetic forces and the coming and going of spots on the sun is the best established fact in connection with the whole problem that concerns the influence of sunspots on the earth. Had it not been for this well-established magnetic connection,

scientists today would have been more skeptical as to whether or not there are any real grounds for believing that spots on the sun nearly 100 million miles away could have any effect at all upon this little planet on which we live. It is all the more remarkable that this relationship should have been discovered and accepted years before we had any theory or hypothesis to explain why.

It was not until we were well into the twentieth century that any material advance was made in bridging the gulf of our ignorance as to why there can be a magnetic effect upon the earth due to sunspots. This bridge of knowledge is still far from completion, but we do feel that the fundamental structural pieces have been laid so that we can almost feel our way across on the naked girders in our search for the connection between sunspots and the earth's magnetism.

This bridge of knowledge which is being built rests its span upon recently acquired information both at the earth end and at the sun end.

The new knowledge that has its foundation in the earth end of the span came into being through the discovery of radio. In the early days of wireless it was thought that the electric waves which carried the telegraph messages without wires traveled in straight lines over the earth just as light waves do. With this conception, it was reasoned that one could never hope to communicate over very great distances, since the

curvature of the earth would prevent the passage of the waves as its huge hulk bulged up into the communication paths.

The earlier wireless engineers thought that by building higher and higher antennas they might perhaps ultimately communicate over a thousand miles or so. In those days it seemed an impossible task to think of erecting sufficiently gigantic structures to lift antennas high enough to send the ethereal waves across the Atlantic Ocean.

How amusing this appears when today any of us can turn the knob on our short-wave sets and bring in broadcasts from Rome, London, or Berlin. Of course, the earlier crude notions about the way in which electric waves travel were erroneous, but such is the way in which science has groped into the unknown.

Perhaps the discovery that this picture was a wrong one came accidentally. Somebody experimenting with wireless and listening in found himself unconsciously eavesdropping on Marconi waves from far-away Europe. Instantly the thought about how wireless waves travel had to be changed. Evidently these atmospheric waves followed the curvature of the earth and did not travel in straight lines after all.

Two electrical wizards, one an American and one an Englishman, caught the picture of what was happening. They both hit upon it at very nearly the same time.

One of these was Professor Arthur E. Kennelly of Harvard University and the Massachusetts Institute of

Technology. Professor Kennelly advanced the hypothesis that the upper region of the earth's atmosphere somewhere about 100 miles or so up must be alive with electricity and that the wireless waves shooting with the speed of light from the powerful antennas spread in all directions until they hit this electrified sky. There they are reflected and bounce back to earth again.

So the earth's atmosphere forms a conducting layer and imprisons the radio waves between the earth's surface and space outside. The wireless waves are confined between the earth and the atmospheric ceiling very much as one's voice is confined within the walls of a speaking tube which connects the drawing room and the servants's quarters in a mid-Victorian mansion.

A very few months after Professor Kennelly published his idea, the English scientist Oliver Heaviside announced a similar conclusion quite independently. In honor of these two distinguished scientific men, the upper region of the earth's atmosphere that is electrically ionized by the sun's radiation is referred to as the Kennelly-Heaviside layer. Nowadays this terminology is applied more exactly to a particular layer about 100 miles high which seems to be chiefly responsible for turning back to earth the radio waves or frequencies from 500 to 1500 kilocycles—the range properly known as the broadcast band.

Now, with the conception of this ionized region in the earth's atmosphere, it was seen that numbers of electrical ions in this region constituted electric cur-

rents. These atmospheric currents flowing about the earth induced magnetism within the earth itself, and therefore any change in the flow of electrons and ions over the surface of the spinning globe would certainly have its effect on changes in the earth's magnetism. To explain then why sunspots affect the earth's magnetism, we need only to suppose that in some way these sunspots change the ions in the earth's upper atmosphere. With any changes taking place in the electrical charges in the upper air, we should expect to find corresponding changes taking place in the earth's magnetism.

There are two theories to explain how changes on the sun affect the electrical state of the earth's upper atmosphere. One of these is that every once in a while there are flashes or flares of ultraviolet light from regions on the sun in the vicinity of sunspots. These intense bursts of ultraviolet light striking the earth's upper air expend their energy in adding ionized molecules of oxygen and nitrogen, thus increasing the electrical state of the high atmosphere. We do know that when light of very short wave length or high frequency hits molecules of gas in such a rarefied region as must exist beyond the stratosphere, molecules will be ionized in just this way, for laboratory experiments have proved it. As the newly manufactured ions start flowing toward the magnetic pole, creating vast rivers of turbulent electrical waters, they generate magnetic forces which will add to those which the

earth already possesses, and a magnetic storm results. These magnetic storms are sometimes so violent as to upset the recording instruments in the magnetic observatories, often causing the automatic pen which writes the records to pass clear off the scale of those sensitive instruments, just as heavy earthquakes will throw the records off the paper of the earthquake recorders in the seismological laboratories of the world.

Another theory is that in the centers of sunspots the magnetic forces are so great that they whirl electrons, or tiny particles, off the sun, which hurtle through space striking the earth's atmosphere and ionizing it with the consequences pictured above.

With the conception of this intriguing ionosphere surrounding the earth, we can see why it is that the compass needle deviates slightly to the east at sunrise and to the west at sundown. You see, the side of the earth which is receiving the sunshine is the side which has the more heavily ionized atmosphere. The effect of these moving ions is to create a magnetic field that will apparently draw the compass needle toward the sun at sunrise. As the sun sets, the highly ionized layer of daytime starts to dissociate, and the effect is in the opposite direction from what it is in early morning. The compass needle is now drawn slowly toward the west. Later it retreats, reaching its normal position by midnight. It is due to the alternate lightening and darkening of the upper atmosphere of the earth as the earth rolls on its axis before the sun that ions are formed

on the daylight side of the globe, some of which will dissociate or evaporate as soon as the sunlight is withdrawn and night comes on.

There is thus a continual ebb and flow of electric currents in the air above us—100 miles, 200 miles, 300 miles high. Like giant ocean currents they stream from the equator to the pole, changing their course with the changing amount of sunshine and becoming violently disturbed when huge sunspots belch forth and rain corpuscular shrapnel in the earth's direction.

With the appearance of unusually large sunspots, therefore, we may expect unusually great disturbances in the ionosphere; magnetic storms result. The delicate little needles of the magnetic observatories flip to and fro violently disturbed and agitated by happenings on the sun; meters for measuring the magnetic forces of the earth show marked increases and decreases in the strength of the earth's magnetism.

Every time the magnetic force changes, it in turn induces currents of electricity within every favorable conductor under its grasp. So electric currents due to changes in the earth's magnetism surge over the long cable lines between New York and Europe which mask the feeble currents carrying the important messages or comments of the press. Changes in the earth's magnetism likewise throw their effect back upon the mass of the electrons in the atmosphere above it. They, in turn, redisturb the earth's magnetism, and days may elapse before the effect of a single huge sunspot

subsides and the earth's magnetic field is normal again.

Is it possible that these magnetic disturbances can affect the flow of electrons and the delicate fibers of one's nerves and brain cells? We do not know. There are so many other disturbing factors which can change one's physical and psychological condition that it would probably be very difficult indeed to gain sufficiently careful data to justify conclusions in this direction at the present stage of science. One thing appears to be certain—that researches in modern medicine and in the nature of electricity and structure of matter are making us more and more electrically conscious and, in turn, explaining our very consciousness in terms of electricity.

Not long ago I was showing a visitor through our laboratory, wherein it has been possible to trace the effect of sunspots on radio transmission. He was astounded that affairs on the sun appeared to have such intimate relationships with radio. Suddenly he stopped his conversation, turned to me, and said, "I would like to ask you a question. Can radio waves from a broadcasting station have any effect on the flight of homing pigeons?"

Now this question set me thinking along lines entirely different from those on which an astronomer is accustomed to think. I am no connoisseur of homing pigeons. As a scientist, however, I refrain from saying

"no" to any honest inquiry, where I have no scientific evidence to support a negative. So after some hesitation, I replied, "I don't know, but why do you ask?" Here is his story:

"I have been a pigeon fancier for more than twenty years and have invested thousands of dollars in the game. I have had some very expensive birds and some records of wonderful scores in my time. However, since the new radio broadcasting station was put in within a mile of my lofts, I simply have not been able to get any scores out of those birds at all. Now, do you think that there is any possible way in which the radio waves could confuse the birds so that they may have difficulty in finding their way home?"

"You have an extraordinarily interesting story," I remarked. "There are times when many interesting questions in science are on the borderline between fields of investigation—a sort of 'no man's land'—where we have very little data. I can at best but speculate.

"I do know that one of the most enticing fields of research is in the province of biophysics where we are told that every movement of a muscle, every heartbeat, and every image received on the retina of the eye is but the transmission of an electrical impulse in the very sensitive nerve fibers that comprise our nervous system. Of course, one of the most puzzling things in biological behavior is this thing called instinct. Of

all the various instincts, the homing instinct of the carrier pigeon is one of the most remarkable."

Ever since the visit of my interesting pigeon fancier, I have been seeking information from acquaintances who know far more than I about the habits and records of these birds. One man tried to assure me that they travel entirely by the sight of familiar objects. I am firmly convinced, however, that this cannot be the case. I am told by a Belgian friend who has been familiar with the game in the old country that the birds can be transported 400 or 500 miles, under conditions where it is impossible for them to survey the intervening landscape.

Furthermore, Thomas Ross, army pigeon expert for the Signal Corps of the United States Army, at Fort Monmouth, New Jersey, has recently succeeded in developing a breed of pigeon that will fly at night. The World War is fraught with records of spectacular flights under conditions of fog and other bad weather. In one instance a wounded bird, blind in one eye, accomplished its flight apparently unperturbed.

There is one characteristic in the behavior of the bird at the outset of its homeward journey which appears of marked significance: When the birds are released from their containers, they soar rapidly upward, cutting huge circles of many revolutions; then they strike out for the home loft. This peculiarity set me thinking of some possible electromagnetic hypo-

thesis which would do for the pigeons what the magnetic compass does for the mariner on the high seas.

Every lad who has studied physics knows that an electric conductor, such as a loop of wire, turned in a magnetic field will produce a flow of electricity in the wire. One of the classic demonstrations of the physics teacher is to place a coil of wire on an ordinary table, connect it to a sensitive current meter or a galvanometer, and turn the loop over. Everyone watches the resultant kick in the recording instrument. Now, the coil of wire need have no connection whatever with any battery or other source of supply. The very movement of the coil cuts through mysterious lines of force of the earth's magnetic field, which are everywhere present. That is what produces the electricity.

In Lindbergh's flight to Paris, this renowned aviator made use of the so-called induction compass, which was merely a device utilizing a coil of wire carried by the airplane through the earth's magnetic field. Thus it generated a certain amount of current, which in turn was recorded by a sensitive meter on the instrument. If the plane got off its course, this coil would cut through the magnetic lines of force in a slightly different direction, resulting in a change in the amount of current generated. This would at once be detected by the meter.

Have we, in the induction compass, an analogy of some sensitive nerve mechanism which Nature has installed in the carrier pigeon?

When a carrier pigeon is taken from its home loft and transported to a different station, these sensitive nerve fibers must cut through the earth's magnetic field with certain definite reactions quite independent of the method of conveyance and dependent only on the distance and direction in which the bird is transported.

When the bird is released, he soars upward and swoops around in large circles until, let us say, the minute electrical reactions give him the "feel," all unconsciously, of the earth's magnetic lines of force. In his homeward flight he thereupon follows such a path as will reverse whatever effect has been produced in his nervous system by the outward transportation. May not some such reflex mechanism take him back sufficiently near to the environment of his loft for his other senses to carry him through to his destination?

The fact that when a bird is transferred to a new loft some ten days are necessary for it to become "home-minded" as to its new location may have some significance in connection with any magnetic field theory for explaining the homing instinct.

All of this, of course, is purely hypothesis born of speculation, insufficiently sustained as yet by experiment for us to state any definite conclusions. Some such hypothesis, however, may prove fruitful in guiding experiment which should enable one to say whether or not there is any likelihood of its being correct.

To come back to the possible effect of a radio station upon a bird's homing intentions, we need only add that

the electrical field of a powerful broadcasting antenna might very well so seriously disturb the nervous mechanism of the bird that the directions recorded by its subconscious "galvanometer" are seriously in error. The confused bird, therefore, is long delayed in his return flight or perhaps lost altogether.

I was telling this story recently in New York. One of the men present at that time told me that a friend of his had had a similar experience—he had lost birds and obtained poor scores after a broadcasting station had been installed near by.

Now, there comes to my desk a letter telling of the experience of Mr. M. H. Paget of Youngstown, Ohio, a well-known fancier and breeder of birds.

Not long ago Mr. Paget, in company with five others, conducted an experiment in Youngstown in conjunction with radio station WKBN, located on top of the Y.M.C.A. building. Sixteen birds were released from the roof of the building early in the morning when the station was off the air—not only birds from the vicinity of Youngstown, but also some from out-of-town lofts. The sixteen birds circled but a few minutes and then were all off in an eastward direction.

One Cleveland bird got home in two hours, flying a distance of sixty miles air line. One Pittsburgh bird reached home in two hours fifty-two minutes, with a flight of sixty-five miles air line. One bird from Warren, Ohio, apparently strayed and did not reach home until

the following morning, although Warren is but sixteen miles from Youngstown.

Station WKBN then went on the air, and sixteen other birds were released, within 100 feet of the antenna. Unlike the performance in the previous try, these birds flew around in circles for nearly half an hour, apparently finding it difficult to get away or to decide on the direction for flight. Ultimately they scattered in all directions. The fanciers appeared so absorbed in the strange performance of the birds that "could not get away" that no attempts apparently were made to check their subsequent "homing" times.

An experiment was recently conducted in the summer of 1937 by Mr. Karl Hassell of the engineering staff of the Zenith Radio Corporation, and J. B. Baggaley of Winnetka, Illinois, who was in charge of a government homing pigeon training loft during the World War. It is reported that a well-trained homing pigeon was released within the vicinity of the transmitter of radio station WBBM, Chicago, operating on 770 kilocycles and with the power of 50,000 watts. The bird rose to a height of about 200 feet, made only a partial circle, and started directly for home, the loft being about six miles from the broadcasting station. When a young bird that had never been away from home was released under the same conditions, he circled twice and started off directly for home. A similar experiment was repeated in the vicinity of WJJD, 20,000 watts, and operating on a frequency of

1130 kilocycles. The results were similar except that the younger bird circled several times and then apparently started off in the wrong direction. He was found, however, in the home loft before the experimenters reached the coop. Apparently no attempt was made to compare results when the radio station was off the air, so that the results leave much explaining still to be desired before any definite conclusions can be drawn.

To determine definitely whether or not radio waves have any effect upon the behavior of carrier pigeons, many carefully planned experiments should be performed, scientifically conducted with all of the precision which would be followed in the laboratory. Measurements of the intensities of the electric field of the antennas, the exact number of minutes spent by the birds in circling with the radio station on and off the air, the directions taken by the birds in both instances, and their times of arrival at the home loft are all important points for consideration.

When such experiments have been reduced to definite numerical data, they may go a long way toward an electric explanation of this mysterious thing called instinct, that guides so many birds and animals on their migrations.

If magnetic and electric forces should enter into the mechanism back of the homing instinct of the carrier pigeon, and if radio waves can so distort the electric and magnetic forces as to affect the birds' direction

finder in the manner indicated, is it going too far to wonder if sunspots which disrupt cable and telegraph lines and set the compass needle vibrating have also effects on the delicate mechanism of brain cells and nerve fibers in intelligent beings?

Perhaps some pigeon fancier with the longest record of flights to his credit will undertake to see if there is any correlation between his scores in certain years and the numbers of sunspots or of magnetic storms.

CHAPTER X

Where Sunspots Grow

WHAT are these things called sunspots?

"What do they look like?"

These are questions that are often asked me when the conversation drifts to the sun and human affairs.

Evidently if weather, radio, magnetism, and human psychology follow the ups and downs of the sunspot market, the more we can know about sunspots themselves the better we may hope to find some mechanism that may explain the dependence of things on the earth upon things on the sun.

One who has had the fun of watching the growth of sunspots during the present rise to maximum is fascinated with the mysterious way in which these disturbances appear and disappear on the sun's disk.

It doesn't take a giant telescope to see sunspots. One can now buy, for as little as twenty-five dollars, an excellent and substantially mounted achromatic telescope which will show sunspots. Of course, one doesn't look directly at the sun through the telescope, for its brilliant light would be injurious to the eye. It is necessary only to point the telescope directly toward the sun and center it by its shadow on a piece of

cardboard held at six or eight inches below the eyepiece, and, behold, you have an image of the sun there just as you have the image of the landscape on the ground glass of a camera.

Scarcely a day passes now when you will not find one or more little dark spots on the sun's disk that move with it, showing that they are actually part of the sun's surface itself. A tiny little spot in a few days may grow to be a group of spots a tenth the diameter of the solar disk. Each day's observations will find them slowly moving over the sun, carried by the motion of the sun as it rotates on its axis. A spot will completely cross the disk in about a fortnight.

There is something very remarkable in the region where these spots grow on the sun. At the beginning of a sunspot cycle, as in 1933, spots first begin to appear in zones north and south of the sun's equator, corresponding to middle latitudes on the earth. As the sunspot cycle progresses, spots begin to appear at lower latitudes. By the time they finally disappear at the end of the cycle, they will occur very close to the sun's equator.

When the next cycle starts about 1943, the new spots will appear again at high latitudes around 40° on either side of the sun's equator and will drift again toward the equatorial region as the next cycle progresses. This drift of the spots in latitude has been observed so many times that it appears to be a law of their behavior.

Sometimes a very large spot will persist for weeks and even months, surviving several complete rotations of the sun on its axis. The longest lived spot on record occurred in 1840. It persisted for eighteen months.

From the rate of motion of the spots that appear at different latitudes on the sun, it is found that the sun rotates much more rapidly at the equator than it does toward the poles. This shows that the surface of the sun in which the spots grow is a wholly gaseous or vaporous phenomenon.

Sometimes sunspots appear in pairs. One of these is likely to be larger than the other, and not infrequently there is a sprinkling of small spots around the generally disturbed region. A really large group of sunspots will often stretch out in an east and west direction, covering an extent of 200,000 miles. With large telescopes under the best of conditions, a good large spot may be followed to the edge of the sun where it appears as a depression or a nick in the circumference. Sunspots have been observed ever since the invention of the telescope in the early part of the seventeenth century, but we did not know very much about their nature until the earlier part of the present century.

It was in 1908 when Dr. Hale of the Mount Wilson Observatory first demonstrated that sunspots were giant cyclones in the sun's atmosphere and were very similar in their formation to the tropical hurricanes and whirlwinds which often originate in the West

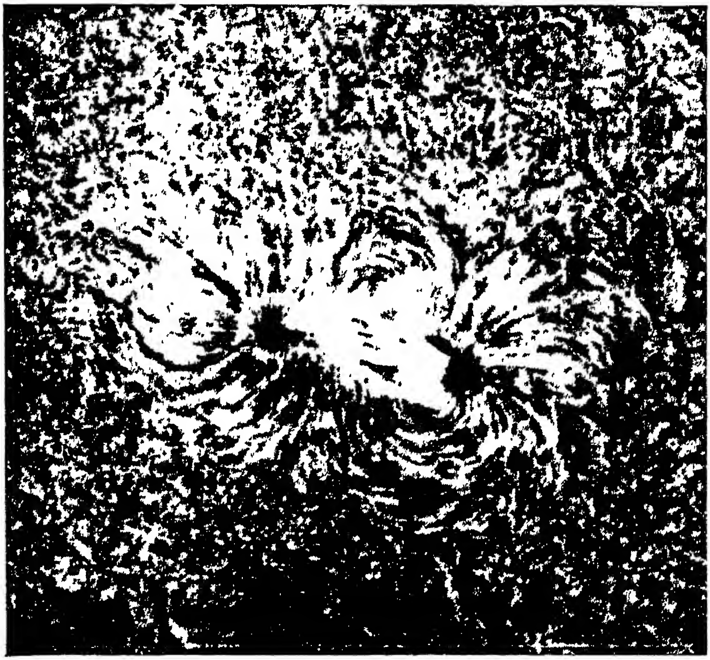
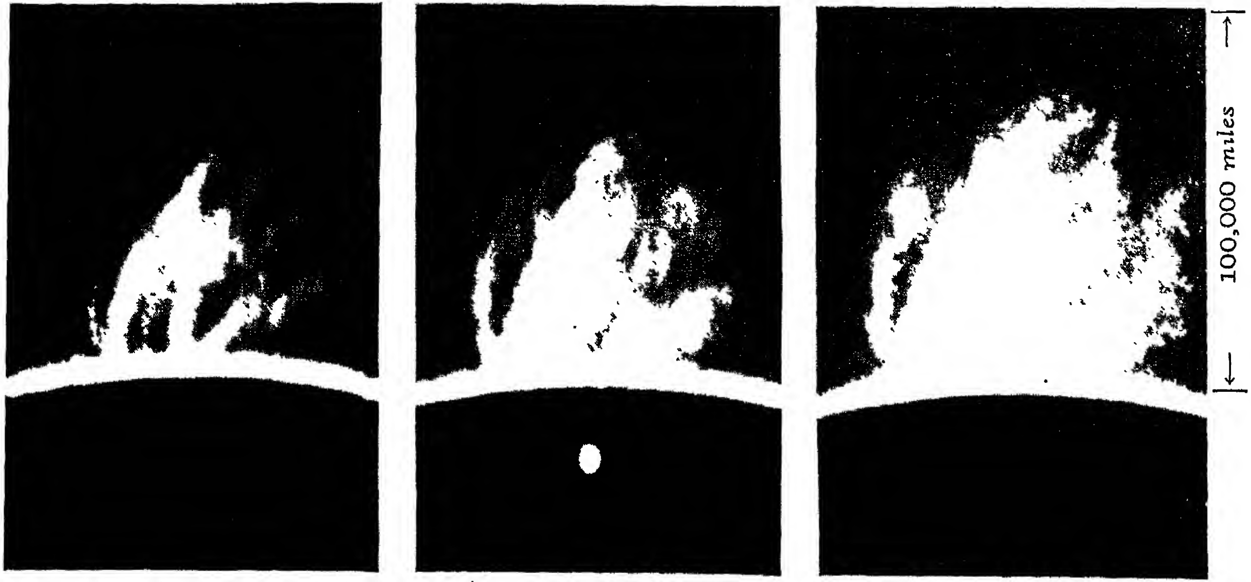


FIG. 12.—A close-up of a pair of sunspots showing spiral-like whirls of hydrogen (Photographed at the Mount Wilson Observatory).



11.48 A. M. 11.55 A. M. 12.03 P. M.

FIG. 13.—The solar explosion of April 14, 1936. Small white disk represents the Earth in comparison. (*Photograph from Cook Observatory.*)

Indies and sweep northward, devastating the real estate markets of southern Florida. An ordinary telescope would never have disclosed all this about sunspots. With a special contrivance, a sort of combination of a spectroscope and an arrangement somewhat similar to a moving-picture outfit, he found out how to photograph the sun, utilizing the light emitted from one chemical element at a time, chemicals whose presence in the sun's atmosphere are betrayed by the lines in the spectrum. It had been known since the invention of the spectroscope that hydrogen and calcium, for example, were very conspicuous elements entering into the sun's makeup.

With photographic emulsions especially sensitive to the red light emitted by hydrogen, Dr. Hale photographed on a moving film the entire solar surface so far as it was covered by bright luminous hydrogen clouds. When he found the trick for doing it, the process took but a very few minutes.

The resulting photographs appeared very different from any ordinary photograph he had ever seen before. There were large blotches of hydrogen gas discernible all over the sun. In the neighborhood of the sunspots they seemed to be swept into the center of the spot as though they were caught by a veritable whirlpool. The picture of a sunspot taken in this way showed the same kind of whirlpool vortex as one often sees when a basin is being emptied of water by the sudden removal of the drain plug at the bottom of the bowl.

Dr. Hale noted that sunspots north of the equator whirled in one direction, while corresponding spots south of the equator were whirling in exactly the opposite direction. This, again, is a close analogy with the meteorology of tropical cyclones on the earth. Owing to the rotation of the earth, it is found that, when a really good hurricane makes up in the northern hemisphere, the clouds and winds spiral about the hurricane center in a counterclockw se direction. In the southern hemisphere the direction of the whirlpool is that in which the hands of a clock move.

If we could imagine an aerial photographer going aloft 20,000 feet and photographing the top of a tornado or a waterspout just as the plane was over the storm center, we might expect to get a picture of tortuous clouds caught in the whirlpool of the cyclonic winds that would look very much like the pictures of sunspots obtained by the Mount Wilson method.

What, then, are sunspots? Terrific storm centers on the sun, cyclones, hurricanes, often covering billions of square miles and dwarfing to insignificance the most violent tropical hurricane, or the worst China Sea typhoon, that has ever happened in the world's history.

Had it not been for the trick of splitting up sunlight into isolated frequencies by means of the spectroscope, we should never have had pictures showing the existence of solar vortices such as we have today. In an ordinary photograph of the sun, the light emitted by

every chemical element in the sun's atmosphere is clamoring to tell us its story. The result is a rather blurred picture of the sun's atmosphere. The spots show up as dark regions in the ordinary photograph only because the light-emitting power of every element in the sun is damaged in the vicinity of these violently disturbed regions.

You see, the spectroscope is very much like a highly selective radio receiving set. Remember, the sun is a high-powered station sending out light of all wave lengths and frequencies. When we look at the sun or photograph it with the telescope alone, we are, so to speak, operating a radio receiver which admits all frequencies at once. Thus we get a composite but very jumbled picture of what is happening on the sun's surface. By means of a spectroscope, the photographic apparatus may be tuned to a single frequency such as the 470,000,000-megacycle frequency that hydrogen light broadcasts. The spectroscope stills the tumult of all unwanted elements and lets hydrogen tell its own story. It is then that we obtain clear photographs conveying the beautifully detailed information about solar storm centers that is otherwise lost in the jumble of too many storytellers.

Another brilliant discovery came from the Mount Wilson Observatory at about the same time. It had long been known that the frequencies of light waves were distorted if there was a powerful magnetic field at the light source. When the Mount Wilson observers

examined and actually measured the frequency of the light coming from the centers of sunspots, it was found to be distorted in exactly the way that light waves are distorted in the laboratory when a powerful electromagnet is placed around a source of light. Thus came the startling revelation that sunspots were not only terrific hurricanes, but every hurricane center was in itself a powerful magnet. This is the discovery that helped to explain the connection between the appearance of sunspots and changes in the magnetism of the earth.

What can produce these strong magnetic fields in the centers of sunspots? If the hydrogen atoms whirling around in vortices carry electric charges just as the molecules of oxygen and nitrogen in the earth's atmosphere frequently do, producing thunder squalls, then it is very reasonable indeed to believe that these hydrogen ions in the sun, circulating about the sunspot center, really carry with them strong electric currents.

It is familiarly known that an electric current flowing around a loop of wire creates a magnetic field within the loop. This is the principle which operates in the electric generator that charges the batteries of your car.

Sunspots therefore appear very definitely to be generators of electricity. The evidence for it is the magnetic field which they create. By the amount of the distortion in the frequency of hydrogen light produced by a known magnetic field, one can make

comparisons with the distortion measured in sunspots and thereby actually calculate the strength of these solar magnets. Every day since this remarkable discovery of Dr. Hale's, the observers at the Mount Wilson Observatory have been recording and measuring the magnetic fields in sunspots. The magnetism in some sunspots is nearly a million times as powerful as that of the earth.

The year 1912 brought the end of the sunspot cycle in which these remarkable discoveries were made. The same year was marked by the beginning of the next sunspot cycle which came to an end in 1923. As the astronomers atop Mount Wilson measured the magnetism in the few spots that could be found throughout that year of minimum (1912), they observed that the sunspots of the new cycle began to appear at high latitudes, and they were astounded to find that these new spots possessed a different kind of magnetism from that of the spots that were passing in the old cycle.

Just as there are two kinds of electricity, positive and negative, so two kinds of magnetism are recognized. The kind of magnetism which attracts the north end of the compass needle is called negative; the kind of magnetism which repels the north end, but will attract the south end, is called positive. There was actually a reversal of the magnetism in sunspots from positive to negative as the old cycle passed into the new.

It was therefore exceedingly interesting to watch what would happen in the year 1923 when another sunspot cycle came to an end and a new one again started. True to expectations, the magnetism of the sunspots reversed again. This led Dr. Hale to announce that the real cycle in sunspots might be twenty-three years rather than eleven and one-half years, for it was obvious that twenty-three years elapsed from the time when sunspots of a given kind of magnetism began to return with the same kind of magnetism again.

Has the kind of magnetism in sunspots anything to do with the twenty-three-year cycle which Professor Douglass has found so prominent in the growth of trees and Dr. Abbot has seen persist for many years in recurrences in the weather? What possible effect can magnetism in sunspots have upon the earth? Although the strength of this magnetism is a million times that of the earth, the sun is so far away that the effect on the earth of these solar magnets appears to be so feeble that we can hardly see how this in itself would ever disturb even a delicate compass needle.

On the other hand, these powerful magnetic fields within the sun's atmosphere may have very much to do with the ejection of electrons, charged particles, or corpuscles which may be speeding from the sun earthward, hitting the earth's atmosphere and there doing the damage which produces the measured effects on the earth.

It has often been noted that when magnetic storms take place on the earth a particularly large sunspot may be in evidence. As a general rule, however, this sunspot appears to have passed the center of the sun's disk, so that if particles emitted from the sunspot's center have been streaming earthward, they must have been traveling considerably slower than the velocity of light to produce their effect on the earth. This is assuming, of course, that the maximum effect of the sunspot occurred when it was near the center of the sun and in line with the earth. It has been estimated that the greatest disturbance in the earth's magnetism occurs from one to four days after a spot has passed its central position on the sun.

In spite of some theoretical difficulties, there appear to be good reasons for believing that there are charged particles or corpuscles emitted from the heart of sunspots and that the magnetic field in the spots is the repelling force that starts them on their way. It often appears that there will be some spots on the sun when no comparable magnetic disturbance takes place on the earth. Perhaps sunspots emit their volley of corpuscles somewhat in the way that a rotating lawn sprinkler spreads its jet of water. As sunspots swing high and again swing low, as they pass the sun-earth line, we may not always be in a position to receive the larger part of the stream of corpuscles ejected. Under these circumstances, a sunspot would not produce its expected effect on the earth.

There are other phenomena on the sun closely related to the sunspots. Very brilliant white cloud-like patches often occur in the vicinity of a sunspot group. They are composed of hot, brilliantly luminous masses of hydrogen or calcium vapor, floating in the high atmosphere just above a sunspot. These white spots are the faculae mentioned in an earlier chapter.

Then, again, enormous explosions of hydrogen gas occur, rising sometimes 100,000 and sometimes 200,000 miles high in less than an hour's time. Perhaps these explosions often occur independently of sunspots and are equally productive in sending us a flare of ultraviolet light or other emissions that produce disturbances in the earth's atmosphere. These so-called eruptive prominences are always more numerous and violent at the time when the sunspots are most numerous. On the rare occasion of an eclipse of the sun, they may be seen projecting from the sun's edge as gorgeous red flames. The prominences take place in the upper atmosphere of the sun that overlies the cloudy areas in which the spots themselves seem to form. It appears that this upper atmosphere of the sun cannot be more than one one-hundredth and probably not more than one one-thousandth the density of the earth's atmosphere. But this, again, is not by any means the limit of the solar appendages.

Stretching far out and beyond the highest prominences is the solar corona which may be observed only at a total eclipse of the sun. The corona may extend

literally millions of miles. It presents a greenish pearly light and has been one of the most baffling problems for students of the sun. The eclipse which happened in the South Pacific in June, 1937, was of about eight minutes' duration. This is the maximum limit during which astronomers are able to study the sun's corona.

The shape of this corona appears very differently at times of sunspot maxima from what it does at times of sunspot minima. Eclipses occurring while spots are very numerous, as in June, 1937, show the corona extending more or less uniformly all around the globe of the sun, whereas at times of sunspot minima the corona extends farther from the sun in the region of the solar equator than it does near the poles.

Oftentimes beautiful filaments appear to diverge from near the poles of the sun, like festive streamers. These distribute themselves very much the way iron filings will distribute themselves about a magnetized steel sphere. Such phenomena appear to indicate that the whole sphere of the sun has a magnetic field very much as has the earth. In fact, earlier observations of Dr. Hale at the Mount Wilson Observatory seemed to substantiate the claim of the sun to a considerable magnetic field of its own. More recently, however, observations have been somewhat conflicting in regard to this.

We probably may never know just how far out in space the solar corona stretches. Perhaps the earth itself is somewhat engulfed in this outer envelope of

the sun. When sunspots are numerous, and solar radiation and particularly the ultraviolet are intense, it is not unthinkable that changes may take place in this far-reaching corona of the sun, extending even to the vicinity of the earth, there forming a cloud of ions that is a contributing cause to the electrical state of the earth and its atmosphere.

One thing is certain—there is every indication that the earth responds to the changing state of the sun over an interval of about eleven years. Whether all of the effects produced in the earth and its atmosphere that are noticed at sunspot maxima are the result of the sunspots themselves, or whether the state of the sun and its whole surroundings are so activated as to change the cosmic environment of the earth, is still open to debate.

It seems probable that while the sunspots may contribute their part in ejecting electrified particles in the earth's direction, the radiation of the sun is changed both in quality and in amount. With any violent disturbances in the solar atmosphere accompanied by brilliant bursts of ultraviolet light, the earth's atmosphere and its magnetism almost immediately respond.

Our present knowledge of the sun, in spite of the fact that it is the nearest of all stars, leaves many of these questions open. With a more complete study of the sun and its sunspots and of the changes taking place on the earth and its atmosphere, and the effects of these upon the world in which we live, we may hope

ultimately to gain a more satisfactory picture of the relationships between the sun and the earth than we can form at the present time.

Enough has been said to indicate that it is immensely desirable to predict sunspots with all the accuracy that our somewhat scanty knowledge will permit. Why sunspots should form, grow, and disappear and what makes them are questions awaiting the following pages.

CHAPTER XI

Can We Predict Sunspots?

WHEN is the next sunspot maximum due? If the answer to this question were as simple as adding the eleven years, the average length of the solar cycle, to the date of the last maximum, the answer would be as easy as two and two. The next sunspot maximum would then be due in 1939.

There are good reasons, however, for believing that this is not the best prediction. I have just been examining the records of the last 180 years of sunspots. In this interval there have been sixteen completed cycles since the well-determined minimum of 1755. The average length of time from one sunspot maximum to the next over this interval is 11.13 years. It is a surprise, and a bit disconcerting, to find that only four maxima of the last sixteen have fallen within eleven years of each other. Three have been spaced 13 years apart; three, 10 years apart; and two, at 12-year intervals. Two others were separated by 8 years, and there was one instance of 16 years elapsing between two adjacent sunspot maxima.

On these grounds alone there would be a chance that the next sunspot maximum might follow any-

where from eight to sixteen years after the last maximum which occurred in July, 1928. There is only one chance in four that the 11-year interval will work for predicting the present coming maximum.

Somebody with a gambling instinct may like to put stakes on the year of the coming sunspot peak. Surely the exciting variations in spots from week to week as they surge up and down on the way to the top should give one all the thrills of watching a favorite horse go over the line.

If we attempt a prediction of the next sunspot peak on a really intelligent basis, we should take into consideration the behavior of these sunspots during the last few races to maximum before making our wager, just as one might watch the past performances of the entries in the Kentucky Derby before picking an anticipated winner. If I do this, I am putting my stakes on Number 10, that is, a ten-year interval from the last maximum. Here is why.

The race of sunspots from the last minimum of 1933 up to the present moment has been by far the most speedy race to the finish line since the spectacular climb to the sunspot peak of 1870. There was one other sharp peak performance of sunspots in 1778. In both of these earlier cases, only three years elapsed between the previous minimum and the next maximum. On the basis of these behavior patterns, one might even reason that we could have passed the present sunspot peak in February, 1937. As the odds, however,

are in favor of a ten- or eleven-year interval, it is a good guess that the middle of the present maximum will fall due in the early part of 1938.

Strange, isn't it, that there is still so much guesswork in predicting sunspots, when astronomers can predict an eclipse of the sun years in advance with an uncertainty of not more than two seconds. Predicting eclipses and predicting sunspots, however, are hardly in the same category. We know perfectly well the laws of motion of the earth and the moon that make possible the calculations of an eclipse, but we are still very much ignorant of the fundamental laws of sunspot behavior.

Before the days of the discovery of the laws of gravitation by Sir Isaac Newton, the predicting of the positions of the planets was in somewhat the state of predicting sunspots today. The star gazers of the Middle Ages had no adequate conception of how planets revolved around the sun in obedience to a universal law. All they could do was to tabulate planetary movements and, on the basis of what the planets had done in the past, attempt to forecast their future positions. Often they were sadly in error.

It seems reasonable to suppose that however complicated the cycle of sunspots appears to be, there is some underlying law which will ultimately simplify predictions of coming sunspot maxima, as the universal law of gravitation simplified the prediction of planetary movements. Just as astronomers arrived at the laws

of planetary motion from a careful study of all previous observations, so we can hope to get at the laws governing the appearance of sunspots from their characteristic behavior. Thus, while one may feel confident of a recurrence of sunspot phenomena at intervals of a little over a decade, the matter of predicting the exact time of a sunspot maximum is far from solved.

Years have been spent by numerous investigators in analyzing the sunspot curve to discover the various periodicities that may enter into it. When we examine the sunspot numbers month by month rather than year by year, it is important to note that there are secondary fluctuations that occur at more or less irregular intervals. These secondary or minor fluctuations have an important bearing on the prediction of the maxima. Some of these intervals of variation are much longer than the eleven-year cycle. Others are shorter.

Studying the graphs of sunspot numbers for the past 300 years, various investigators have found, in addition to the 11- and 23-year periods, periods of 37, 77, 83, 252, 300, and even possibly as long as 1400 years. Not all authorities, however, will agree as to the reality of some of these intervals. We have hardly enough sunspot records to be sure of any intervals of 100 years or more.

Someone is asking what we mean by sunspot numbers. Thereon hangs a tale. It was the astronomer Wolf at Zurich, Switzerland, who introduced the idea of a

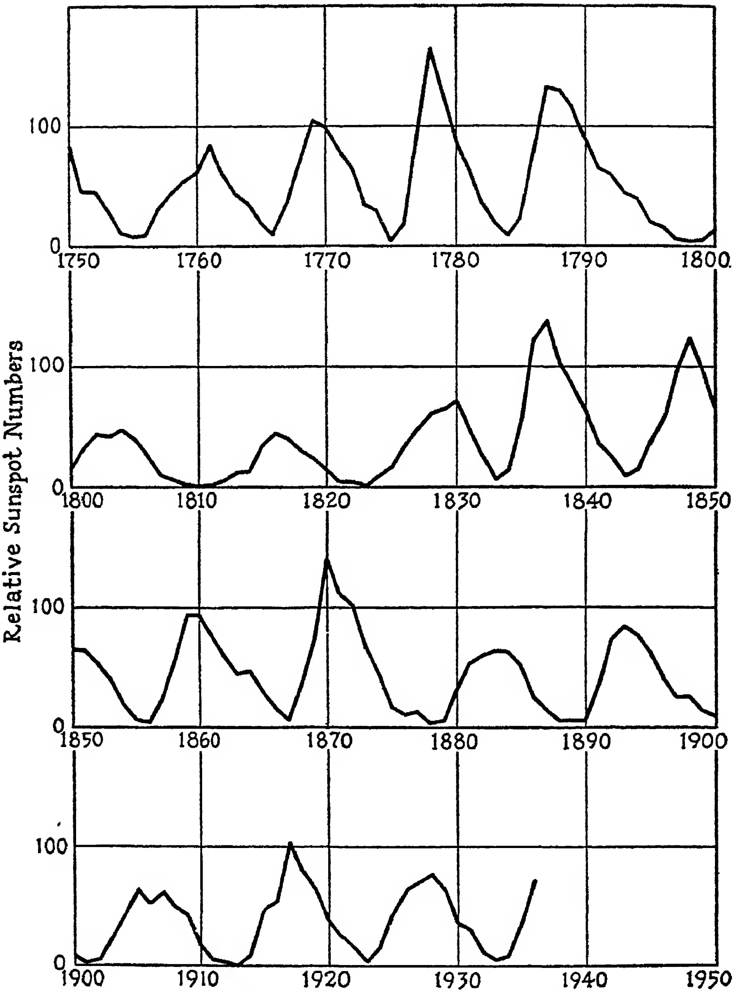


FIG. 14.—Sunspot cycles from 1750–1936.

sunspot number as a sort of index to keep track of the prevalence of spottedness on the sun. Wolf actually counted the number of spots that he could see every day with his telescope. When he found a large number of spots grouping themselves together, he felt that such an aggregation of disturbances was of more consequence in judging solar behavior than the appearance of small isolated spots scattered here and there over the sun's surface. So he added to his count of the numbers of sunspots ten times the number of the groups which he could see at any one time. This combined number, made up of both spots and groups, he designated to be the "sunspot number" for the day. Wolf spent so much time adjusting all observations made by other observers in old records of sunspots and reducing them to a common system that this solar index has come to be known as the Wolf number. Sunspot numbers have been averaged month by month and year by year and have worked out remarkably well in tracing solar activity throughout the years.

The observatory at Zurich continues to receive records of day-by-day observations of the sun from all over the world. There they are reduced and officially published as Wolf numbers. Some difficulty is experienced by observers at different observatories in estimating and deciding when a considerable number of spots may be considered as forming a group, so that sunspot numbers made up in different

places often differ considerably from each other. The monthly and yearly averages, however, are remarkably consistent.

More recently it has been agreed upon to measure the total disturbed areas of the sun every day. The size of a sunspot big enough to be seen with a telescope can easily be estimated. It is customary for observers of the sun to express the total area of all the sunspots observed in terms of a unit area one one-millionth of the sun's visible hemisphere. This is the method adopted by the United States Naval Observatory and the Royal Observatory at Greenwich, England. A good-sized sunspot may range from 700 to 1000 millionths of the sun's hemisphere.

In comparison, think of a good-sized tropical hurricane, raging over the West Indies. This may cover a disturbed area of 70,000 square miles. Since the area of a hemisphere of the earth's surface is 98 million square miles, a typical West Indian hurricane would cover 700 millionths of the hemisphere of the earth. Thus, on the scale of the earth, a tropical hurricane would be comparable in size to a sunspot on the surface of the sun.

The areas of the sunspots on a given day, therefore, may serve as a reliable index of solar activity; the use of areas eliminating the puzzling uncertainty of estimating the Wolf numbers. It is quite surprising, on the other hand, to see that if we make a chart of sunspot areas month by month and year by year, we find very

little difference between this and one made from plotting the Wolf numbers. There is a great advantage in utilizing the Wolf numbers in statistical studies of sunspots, for we have records of these numbers going back to the middle of the eighteenth century, whereas we have comparatively few years of records since the method of measuring the areas of sunspots has been adopted.

The possibility that sunspots may have an important bearing upon the weather led the Weather Bureau to start publishing the daily records of solar observations in the *Monthly Weather Review* beginning with 1927. To make this possible, various observatories entered into cooperation in photographing the sun every day. Now, whether it is clear or cloudy at any given place, we can feel very confident that somewhere in the world the actual record of sunspots has been obtained for every day in the year.

It seems wholly possible that other changes are going on in the sun which do not always show up as sunspots, but which are quite as important in their effects on the earth as may be the spots themselves. The sun is also being watched for faculae, those bright white patches which are seen from time to time, particularly in the vicinity of sunspots. A record is also kept of the hydrogen clouds and the calcium clouds, for often our radio fade-outs occur with sudden explosions of hydrogen gas on the sun. If we make a chart of the number of these phenomena observed

every day, we find again that the correspondence is very close to the Wolf sunspot numbers.

Each approach to a sunspot maximum always creates interest in this problem of predicting sunspots. At the last sunspot maximum in 1928, the *Monthly Weather Review* published a translation of an article that had appeared by H. Fritz in a German scientific periodical during the sunspot maximum of 1893. Professor Fritz endeavored to trace periods of solar activity as far back as the earliest records would allow. He dug into ancient Chinese documents. He examined the early European observations. Then he tabulated all the probable years of sunspot maxima from A.D. 188 to the year 1626, after which records were more complete and reliable.

It may puzzle you to know how the Chinese were able to record sunspots; the telescope was not invented until the seventeenth century. The reason is that frequently during a sunspot maximum, there will occur spots of such size and magnitude as to be easily seen with the naked eye. Since, however, one never sees such large sunspots except near the time of maximum of solar activity, it appears very reasonable to suppose that when there was a record of naked-eye sunspots in the Chinese annals, the date of that record could not be very far from the year of maximum solar activity.

It is of course possible that years of sunspot maxima often passed when no naked-eye spots were seen. So

Professor Fritz added to his table the years that appeared to him to be the most probable ones for fixing the maxima based on such records as were available. He lists the most conspicuous sunspot maxima of early times as occurring in the years 372, 840, 1078, 1133, and 1372. He noted that these years are separated by eighteen periods of an average length of 55.5 years and believed that this interval could be traced over many epochs.

In 1928, Professor Alter, now in charge of the Griffith Observatory and Planetarium at Los Angeles, made an intensive analysis of the Wolf numbers from 1749 to 1926. Alter found evidence for periods of 68, 84, 126, and 252 years in addition to the 11-year cycle. From his analysis he was able to reproduce quite accurately the sunspot curve from 1750 to 1926.

If Professor Alter's analysis made in 1928 were to be used for predicting the solar activity at the present time, we find we should have had a maximum of sunspots by the end of 1935, and by 1938 we might anticipate a minimum. This is, of course, far from the case, for from 1935 to 1937 we have had one of the most remarkable rises in sunspots on record. Again, Professor Alter's curve indicated that a minimum would occur in 1931, while the actual minimum did not occur until the end of 1933. Certainly the large number of sunspots recorded this past year indicated that the sun did not decide to have its production regimented

by the findings of any brain trust of college professors —just yet.

A year ago on the basis of the occurrence of the last minimum and the present rate of rise in sunspots, I ventured to predict that the next sunspot maximum would occur in the early part of 1938, or a year before what would have been expected by adding eleven years to the time of the last maximum. If my predictions should prove correct, it would be one of the pleasantest and most unexpected turns of fate for which a scientist could hope.

Of course, it is possible that the present solar activity after undergoing secondary fluctuations may continue to ascend to a 1939 peak. Since, however, sunspots have already made records exceeding that of the maximum of 1917, and since, in general, alternate peaks in the sunspot curve are more sharp in their formation than the intervening ones, we should be due for a sharp peak this time. All considered, it does not seem at the present writing that one can possibly believe that the present maximum can carry on much beyond 1938 without a substantial trend downward in the average sunspot number. A twelve-month peak in the secondary fluctuations appears also to be due early in 1938. This may be the cause of the real top for the period.

What appears to be the most remarkable agreement between prediction and observation of the occurrence of sunspots that I have yet seen is to be found in some

recent investigations of Mr. H. H. Clayton, which he has been kind enough to show me while this book was in preparation. From a long and elaborate analysis of all the sunspot numbers available from 1750 to 1910, Mr. Clayton finds that a period of between sixty-eight and seventy years, together with certain fractions of this interval, serves as a basis for an astonishingly close prediction of sunspots for the subsequent years.

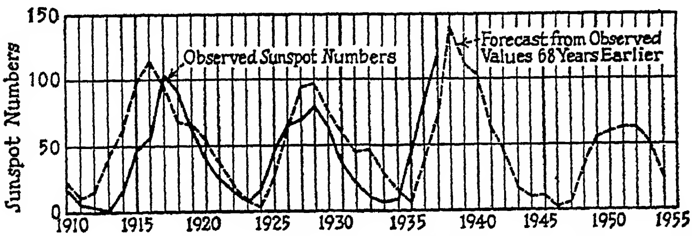


Fig. 15.—Clayton's prediction of sunspot numbers based on the 68-year period.

The actual intervals which he uses in addition to the 68-year cycle and the well-known 11⅓-year sunspot interval are 8½ years, 10 years, 14 years, 17 years, 23 years, and 34 years. Judging the relative importance of these several intervals from the way in which they show up in this analysis of sunspot data, he has actually been able to compute the expected sunspot number each year from 1910 to date. His predicted sunspot curve is shown in the diagram, drawn with the dotted line. The full black line shows the actual observed sunspot numbers over this same interval to 1937. The agreement between this forecast and the observed

values merits close attention. It will be noted that, following Mr. Clayton's predicted curve, the coming sunspot maximum should fall in 1938, quite consistent with the author's prediction which was made in advance of any knowledge of Mr. Clayton's independent method of approach. Mr. Clayton's scheme of analysis not only gives the date of maxima but also the approximate sunspot number for any given year. It will be seen from his prediction that the sunspot maximum in 1938 is due to be an exceptionally high one and that the next sunspot minimum will arrive not far from 1946. The next sunspot maximum of 1951 may be expected to show only half the amount of solar activity of the sunspot maximum which we are now experiencing. My thanks are due to Mr. Clayton for allowing me to present his recent findings in this chapter.

There is an important variation in the characteristic of sunspots of which we should not lose sight. This is the apparent drift in the positions of the spots toward the solar equator as they continue to break out during the whole eleven-year interval. At the beginning of the sunspot cycle, the spots first appear in the neighborhood of 35° from the sun's equator. This was the case in the present sunspot cycle which started in 1934. It was also the case at the beginning of the previous cycle which started in 1923. As the cycle advances, the spots increase in number, but they also appear at lower latitudes on the sun. While they fluctuate back

and forth in latitude from day to day and month to month, the trend is always toward the equator, both for the spots which appear in the northern hemisphere and for the ones which appear in the southern hemisphere of the sun.

As the sunspots approach their maximum, they occur most frequently in solar latitude 15° either side of the equator. After the maximum has passed, the spots decrease in size and number, but they continue to break out at decreasing latitudes. Finally a few scattered spots may be seen either side of the sun's equator at latitudes 2° to 5°. This represents the death of the cycle. Before the last of these small spots has disappeared close by the sun's equator, the new series of spots begins to break out in high latitudes again, thus ushering in the new cycle. The fact that a sunspot maximum is not usually attained until the average latitude of the spots has reached about 15° from the equator leads one to believe that at the present writing the maximum is not yet past but may be expected not far from the beginning of 1938.

This peculiar trend of latitude in the sunspot period is so far without any adequate explanation. A knowledge of the latitude of spots, however, helps very much in diagnosing where we may be at present with respect to the sunspot cycle. Since the present average latitude of sunspots appears to be in the 18° zone, therefore, on this ground alone, it appears that we are fast approaching the next maximum of sunspots, which

will probably occur within a year after the publication of this volume.

As there is sure to be some reader who will be interested in playing his own game of sunspot numbers in his own way, there is printed in the appendix the monthly and yearly values of the Wolf sunspot numbers from 1749 to the date of this publication.

CHAPTER XII

What Makes Sunspots?

If we knew what was the ultimate cause of sunspots, it would probably help very much in solving the mystery of the solar cycle and in predicting the future behavior of the sun. Of course, the spots are fundamentally due to atmospheric disturbances in the surface layers of the sun, but whether or not the cause of these disturbances is to be found entirely within the sun itself may be still a debatable question. The periodic nature of the recurrences of sunspots has suggested to some that the planets in some way were the disturbing bodies, but, so far, failure to predict accurately the activity of sunspots on the basis of planetary cycles has led some astronomers to believe that the fundamental cause of sunspots is to be found entirely within the sun itself.

Any complete theory of sunspots must obviously explain not only why they arise at the more or less irregular intervals of eleven years but also why the first spots of a new series appear in high solar latitudes. It must also account for the slow progression of the spots toward the solar equator as the sunspot cycle advances. Furthermore, since we now know that the

magnetic character of spots changes from one cycle to the next, an explanation is needed for the change in polarity of sunspots in alternate cycles.

To account for many of these observed phenomena in connection with sunspots, a rather elaborate theory was advanced a few years ago by a Norwegian meteorologist Professor Bjerknes. On theoretical grounds, Bjerknes supposes that there is an atmospheric circulation taking place between the outer surface of the sun and the interior in such a way that in the outer layer of the solar atmosphere the gases are flowing from the poles to the equator. Near the equator they fall below the surface and then travel northward to high latitudes. Gaining in temperature, these subsurface currents rise again to the surface around latitude 40° on the sun, then move southward to the equator, gradually cooling until they fall again into the interior as they reach the solar equator again.

Accompanying this circulation on a gigantic scale, Bjerknes postulates, the gases are caught in secondary whirls which extend in a kind of tubular formation resembling that of a hollow rubber hose engirdling the sun in parallels of latitude. As this tubular formation is carried southward toward the equator, it is now and then forced to the surface of the sun where it breaks into two segments, the upper ends of the tube appearing as a pair of sunspots. Since the circulatory motion of the gases in the tube will presumably persist even after this tubular affair has been broken

at the surface of the sun, we should find the circular cross sections of these tubes appearing as vortices rotating in opposite directions. This is in accordance with the usual facts about bipolar, or double, sunspots.

Occasionally, this scientist thinks, one section of the tube might be so disturbed as to make no definite appearance on the sun, and we should have as a result but a single spot. As the tubular vortex is carried toward the equator, it is obvious that when it breaks through the surface, the resulting spots will be seen at lower and lower latitudes. When this circulating tube of gas approaches the parallel of the solar equator, it sinks beneath the surface. Thus a cycle of spots would vanish at the equator.

The author of this theory thinks that probably another vortex rotating in the opposite direction exists in the lower region and that this is carried northward. With the heating of this region, this second rotating tube rises to the surface at about latitude 35°; and when it breaks through, it will form a sunspot or two with vortices rotating in the opposite direction from those of the previous cycle. On the basis of this theory it would take eleven years for a given tubular vortex to descend from high latitudes to the equator, meanwhile bringing to the surface the second tubular vortex for the start of the next cycle. Twenty-two years, therefore, would elapse between the appearance of one of these vortices at the surface and another one rotating in the same direction.

While Bjerknes thus accounts for many of the well-observed peculiarities of sunspots by this theory, he can give no satisfactory explanation of the origin of these circulating tubes of gas, nor is any attempt made in his theory to account for the eleven-year periodicity together with the slight variation in this eleven-year interval.

Many astronomers who believe that the origin of sunspots is associated with the heating and cooling of the gases within the solar sphere incline to the idea that irregularities in the period are inevitable and that it is probably useless to attempt to predict variations from it. There are many variable stars in the sky which change brightness more or less periodically but with such uncertain intervals as to make the prediction of the variations exceedingly difficult, if not impossible.

In connection with the origin of the sunspots, it is most important to remember that the sun rotates more rapidly near the equator than at the poles. In consequence there must be a continual slipping between the atmospheric gases in the lower zones against those circulating less rapidly in the higher latitude zones. This in itself should be conducive to the formation of eddies. We have all noted how rapidly moving water in the center of a stream slips past the more leisurely flowing currents near the riverbank, often causing whirlpools and eddy currents.

If we compare conditions on the earth with conditions on the sun, we see that in our own atmosphere,

tropical hurricanes and cyclones for the most part occur at about the same latitudes on the earth as the sunspots on the sun.

Others who have studied the problem still believe that outside forces acting on the sun are primarily the cause of sunspots. If the planets circulating about the sun are possible sources of these disturbances, then we may well consider to just what extent the planets may have any effect upon the gases in the sun.

The planet whose period of revolution about the sun comes nearest to the eleven-year cycle is Jupiter. Jupiter revolves about the sun in 11.8 years. The average length of the sunspot cycle, however, is but 11.2 years. This difference of more than half a year is so great that it does not appear easy to assign to Jupiter alone the cause of the disturbances on the sun. The usual assumption in favor of planetary influences on the sun's atmosphere is that the attraction of the planet for the sun causes tides in the solar atmosphere as the moon causes tides in the oceans of the earth.

The moon's gravitational pull on the oceans results in a bulging of the water on two opposite sides of the earth. As the earth rotates, a given port will therefore encounter two high tides and two low tides in each rotation of the earth with respect to the moon. To be sure, there is also a monthly tide due to the fact that the moon is for a part of the month north of the earth's equator and for a part of the month south of the earth's equator. There is also unusually high water at the

time the moon is new or full, for then the attraction of the moon and the attraction of the sun on the water of the earth are acting to reinforce each other.

Carrying this earth-moon analogy over to the problem of tides in the solar atmosphere caused by Jupiter, we should expect disturbances of the sun to occur twice during each rotation of the sun. It is difficult to see how the revolution of Jupiter in its orbit once every twelve years could produce a tide only once in this interval, even assuming that the period of Jupiter and the period of the sunspots were the same.

To be sure, Jupiter's orbit is a bit eccentric so that it is sometimes nearer the sun and sometimes farther from the sun than its average distance. The change in its distance, on the other hand, is a little less than 5 per cent. The distance of Jupiter from the sun is 5.2 times the earth's distance from the sun, or approximately 484 million miles. Were Jupiter no bigger or no more massive than the earth, its effect on the sun would appear insignificant. Jupiter, however, weighs approximately 317 times as much as the earth, so that, on account of its mass alone, its effect on the sun is 317 times as great as that of the earth.

Now, it is easy to show mathematically that the tide-raising force decreases with the cube of the distance, so that the total effect of Jupiter on the sun may be only a little more than twice that of the earth. The variation in this tide-raising force, on account of the changing distance of the planet from the sun, is

six times as great with Jupiter as it is with the earth.

If Jupiter has an effect on the sun, it is obvious that the other planets likewise must influence tides in the solar atmosphere. This influence will in each case vary as the mass of the planet and the inverse cube of the distance.

Various attempts have been made to try the combined effects of the planets. Perhaps one of the most notable of these is that of Professor E. W. Brown of Yale, who in 1900 called attention to the fact that approximately every 9.93 years Saturn is in line with Jupiter and the sun, so that the tide-raising force of Saturn, which is approximately one-third that of Jupiter, is added to Jupiter's effect. He combined this 9.93 year interval between conjunctions and oppositions of the planets with the period of Jupiter's revolution about the sun, which is 11.86 years, and found that he could reproduce most of the times of the occurrences of maxima of sunspots. By 1900, however, his curve deviated so much from the sunspot curve that the author himself expressed doubt as to the reality of the agreement. Curiously enough, the subsequent maxima of 1906 and 1917 came very close to the times which would have been predicted from Brown's assumption. However, the maximum of 1929 would have been very far out.

It may be mentioned that in some of the minor fluctuations in the sunspot curve there is at times a very

marked interval of fifteen months between secondary maxima. This was particularly conspicuous during the last solar cycle from 1923 to 1933. It is perhaps worth noting that fifteen months, which are approximately 450 days, almost exactly correspond to two revolutions of Venus about the sun, the period of Venus being 225 days. This is also very nearly equal to five revolutions of Mercury about the sun. One may say with a fair degree of approximation that Mercury and Venus come together on the same side of the sun once every fifteen months. Now, on account of the closeness of both Mercury and Venus to the sun, their tide-raising effect is very appreciable, the effect of Venus being nearly the same as that of Jupiter.

Birkeland made an exhaustive study of the sunspot curve and the effects of Jupiter, the Earth, and Venus. In this way he could account not only for many of the major maximum sunspots but also for many of the minor fluctuations. But in applying his results over a long period it is found that, as is so often the case, actual minima of sunspots occur sometimes when one would suppose on his theory that maxima should take place.

Shuster in 1906 published a most exhaustive paper in the *Philosophical Transactions* of the Royal Society of London which should be studied by anyone who is interested in further details of periodicities in sunspots. From a careful analysis of many years' records, he found various periodicities, none of which corre-

sponded exactly to the periods of any of the planets.

The fact, however, that periodicities in the sunspot curve do not agree with periods of revolution of the planets about the sun does not appear to me as necessarily excluding planetary influences. An important point which seems to have been overlooked thus far in all such investigations of tidal action is the effect of the sun's rotation and any natural period of oscillation of the solar atmosphere. On the basis of any accepted tidal theory one would expect that each planet in turn would raise tides, however slight, in the solar atmosphere approximately equal and opposite. The raising of such tidal waves would immediately set the whole solar atmosphere into oscillation, sending an atmospheric wave around the sun which would travel at a speed that would depend upon the density and the gravitational attraction. Each planet, in turn, would start its own similar oscillation, and the composite tidal wave at any moment would therefore depend upon the positions of the planets with respect to each other.

As the sun rotates carrying the atmospheric particles past the point of major attraction, successive pulses would be increasing the amplitude of the waves so long as the period of oscillation of the atmosphere was comparable with the intervals between successive pulses. In this way it is possible that even the slight tide-raising forces of the planets could in the course of time

set up a major oscillation in the sun's atmosphere, very much the way in which synchronized footsteps of a regiment may set a steel bridge asway. Perhaps a homely analogy may clarify the picture.

I have anchored off my summer place in Maine a forty-foot cabin cruiser. It is of sufficient tonnage so that ordinary movements about the boat do not perceptibly set it in motion. Sometimes, as a matter of amusing experiment, I have stood in the cabin astride the fore-and-aft line and allowed my weight to fall alternately first on one foot and then on the other. Now, the weight of 150 pounds pressing on the floor of a fifteen-ton boat, a foot from the fore-and-aft line, produces of itself no perceptible list. Knowing, however, the natural period of roll of the boat and using this as an interval for alternating the pressure from right to left, I can make the boat roll violently in a very few minutes. It can be stopped equally quickly by reversing my movements, thus making the small force which I can exert oppose the natural roll of the boat.

Suppose, now, that the solar atmosphere has a natural period of oscillation similar to that of the boat and that it encounters the slight tidal force of Jupiter twice each rotation of the sun, or approximately once every thirteen days. If the natural period of vibration of the sun's atmosphere is close to the thirteen-day period, then in the course of time the solar atmosphere will become violently agitated so that convection

currents arise within it, causing eddy currents and whirlpools which break out in sunspots. The time that it will take to start the solar atmosphere into a period of maximum oscillation after it has been in equilibrium will depend upon how closely the interval between pulses of the tidal force corresponds to the natural period of oscillation of the atmosphere. It is conceivable that months and years may be necessary for the accumulation of a sufficient number of weak pulses to get the sun's atmosphere into the maximum disturbed state. If the intervals between the tidal-force pulses are not in exact agreement with the free period of oscillation of the solar atmosphere, the disturbances will subside again until equilibrium is attained, after which another period of oscillation will grow to maximum with a subsequent subsidence.

To return to the boat analogy, if the interval between the pressure exerted to the right and left of the fore-and-aft line of the little ship is somewhat less than the natural period of roll of the vessel, a long time will elapse before the boat takes on its maximum oscillation. If we continue to experiment, we soon find that the difference in the intervals between the applied force and the intervals of a complete cycle of roll will work against the very oscillations which the imposed forces set up. The roll of the vessel will gradually die down until it is stationary and then will start up again in another cycle. The intervals between the times of the maximum roll of the vessel depend very definitely on

the difference between the length of the interval of my alternate foot pressure and that of the successive rolls of the boat. The interval between times of maximum roll may be very great indeed compared to the natural period of the roll or of the interval between my alternating foot pressure. Now, let us carry our analogy back to the sun.

Twice every revolution of the sun, a given region of the solar atmosphere encounters the tidal stress of some planet. This interval, as we have already stated, may not be very far from thirteen days. It will be longer than thirteen days for Mercury, which is changing its position rather rapidly on account of its fast orbital motion; and it will be very much nearer thirteen days for Jupiter and Saturn, which are so far out that their leisurely orbital motion makes very little difference in their position with respect to the sun in two week's time. A similar situation will hold for Venus and the Earth.

From the point of view of the tide-producing power, Venus and Jupiter are about equal. On the other hand, Venus moves so rapidly around the sun as compared with Jupiter that the tidal pulses created by Venus may be encountered at too long intervals to agree very closely with the natural period of oscillation of the solar atmosphere. Jupiter, on the other hand, moving much more slowly in its orbit, raises tidal bulges in the sun's atmosphere which will be encountered at but a little more than thirteen-day intervals. If, there-

fore, the natural period of oscillation of the solar atmosphere is such as to favor a thirteen-day interval, Jupiter will have by far the greater effect, although it may take years for its feeble tide-raising force to bring the solar atmosphere into maximum oscillation. We might expect that the intervals between maximum solar disturbances, therefore, should be nearly equal to the period of revolution of Jupiter about the sun; but to be exactly the same would be a most remarkable coincidence.

It would seem that real progress in predicting sunspots from planetary effects may yet come, if, in addition to analyzing the periods of planetary motion, one takes into account the natural periods of oscillation of the solar atmosphere as well.

One might add to this somewhat speculative hypothesis the fact that the zone for maximum tidal stress on the sun occurs near 45° latitude, a region not far from the zone where the first sunspots start at the beginning of a cycle.

If we suppose, then, that it is in these zones of latitudes either side of the solar equator that the oscillatory disturbances are started, there might be a general movement of the particles in the solar atmosphere from these zones toward the equator in either hemisphere, just as there is a tendency due to the tides of the ocean for the water from 45° latitude to flow toward the equator, the region that, on the average, is most nearly under the moon.

As the disturbances start in these zones on the sun and move toward the equator, vertical whirls would gradually be generated as the cross current meets the region of the sun's atmosphere that is moving rapidly westward. These eddies would break out as sunspots in latitudes lower than the 45° zone. This would be in general agreement with the latitude of the first sunspots breaking out in new cycles. The oscillatory motion of the solar atmosphere would gradually be damped out by the lack of complete conformity between the intervals of the pulses of the planetary tidal forces and the natural period of oscillation of the sun's atmosphere. The spots, therefore, might be expected to peter out at the equator at the end of this interval. By the time of disappearance of this series of oscillations, the continued pulses would start a new cycle at high latitudes, thus ushering in the new sunspot period.

Another factor which may enter the situation is the variable rotation of the sun. It may be entirely possible that the period of rotation in latitude 45° which is about twenty-six and a half days is more favorable for the encountering of the planetary tides twice each revolution than is the shorter period of rotation which is experienced at the sun's equator. This would be an argument in favor of spots starting at high latitudes and petering out at low latitudes. There would, you see, be a slowing down of the oscillations as they move into the equatorial region where the shortened period of the sun's rotation kills the natural vibrations which

have been set up. When someone has worked out more completely the free period of oscillation of the sun's atmosphere, such a hypothesis may be put to a more rigid test.

The fact that the atmosphere of the sun in which the spots occur may be a thousand times more tenuous than that of the earth's atmosphere favors a natural period of oscillation of at least several days. Furthermore, the effect of the gravitational attraction of the sun upon the particles in its atmosphere is very considerably minimized by the outward pressure of radiation coming from the interior of the sun. This is another reason for believing there may be natural periods of oscillation of relatively long duration.

CHAPTER XIII

Alongside Singapore—A Résumé

HE was a stocky little fellow that met me in the lounge café aboard the *President* liner that lay at the quay in Singapore. His high forehead, penetrating black eyes, and bronzed skin betrayed his Oriental heritage and yet withal gave the distinct mark of unusual intelligence.

"Do you think," he asked, "that the sunshine of the tropics is necessarily detrimental to one's intellectual ambitions?"

Now, far be it from me to discourage the ambitions of any tropical inhabitant.

"Not necessarily," I replied. "Life began in the tropics or at least in a subtropical climate. Why should it not grow most luxuriantly there in all its forms? Of course, there have been many natural enemies of man in tropical jungles, but science is conquering them. There is no longer an excuse for yellow fever or malaria, and it appears likely that other tropical diseases will soon be under control. One may have to live more leisurely in a warm climate, yet sometimes leisure is productive of the best creative thinking. Of course, it may be that the warm climate has favored the less

fit as well as the fit, whereas in our northern temperate zones, the hardships of winter have eliminated all but the more virile who were the survivors of the fittest and from whom the progressive element of the north has descended."

"Doctor," he said, "I have heard much about the question of sunspots and its possible effect upon us. As a representative of the local press, I want to get a story from you. Just what has science to say as to the possibilities that these sunspots in which you are interested have something to do with human behavior. Do they really affect the earth?"

I glanced at the ship's clock. It was within a few minutes of sailing time. I must be brief, I thought.

So I said, "Of course, there is much speculation in regard to this, but there are certain effects that appear to have been definitely substantiated and which indicate beyond a question that whenever changes take place on the sun in the coming and going of sunspots, there are definite changes that take place in the earth and its atmosphere.

"As the time is short, I will summarize some of the questions for which we have definite answers, and indicate others which will require much investigation before definite statements can be made. It is very important to differentiate between facts and speculation.

"1. We definitely know of the existence of sunspots as terrific cyclonic storms in the solar atmosphere generating powerful electromagnetic fields.

"2. Sunspots come and go in definite cycles of approximately eleven years' duration, a fact which has been established from at least 300 years' observations.

"3. Magnetic changes in the earth are definitely known to accompany the rise and fall of sunspots. This fact rests upon careful observations of variations of the compass and measurements of the strength of the earth's magnetic field for over a century.

"4. Auroral displays are known by actual observations to be more numerous and more brilliant at times of sunspot maxima. That the auroral displays are due to electric discharges in the high atmosphere produced by electrified particles emitted from the sun appears to be the most workable hypothesis to account for auroral phenomena.

"5. The close correspondence between the character of radio transmission and the sunspot numbers appears to lie beyond any reasonable doubt as a result of quantitative measurements made during the last fifteen years.

"6. The theory of propagation of radio waves presupposes the existence of an ionized region of the earth's atmosphere, the ionization of which is chiefly produced by the ultraviolet light of the sun, which may be seriously modified by the bombardment of electrified particles emanating from the sun during the occurrence of sunspots. The fact that the behavior of radio reception responds more closely to the occurrence of spots in the central zone of the sun and, therefore,

near the sun-earth line is a strong argument for a theory of corpuscular emission from the sunspots themselves.

"7. Changes in both the amount and quality of solar radiation with the sunspot cycle have been definitely established by quantitative measurements of the Smithsonian Institution and of the Mount Wilson Observatory of the Carnegie Institution. The Smithsonian Institution has found a 3 or 4 per cent variation in the total quantity of radiation emitted from the sun; and the Mount Wilson Observatory has shown that the proportional amount of ultraviolet light varies from day to day and year to year, the ultraviolet light in general being strongest near a sunspot maximum.

"8. The effect of sunspots upon certain biological behavior appears to have been established beyond contention through the growth of trees whose ring patterns have been definitely shown by Douglass to show the sunspot cycle through the centuries.

"9. The possibilities that the changing quality of solar radiation may affect directly the growth and character of the foodstuffs we eat and the consequent behavior of ductless glands is a problem for future investigation.

"10. The fact that one's physiological and psychological behavior depends upon the movements and charges of the ions or electrified particles in the air we breathe results from certain experiments already performed. The possibility that the movements and character of these ions of the lower atmosphere change

with the sunspot cycle is at present speculative but is open for investigation.

"11. The question of the effect of the solar cycle on the weather is highly complex, but sufficient evidence seems to have been presented to give a basis for believing that storminess on the earth migrates through definite cycles, which follow, in general, the cycle of solar activity.

"12. The dependence of economic conditions upon weather, on the physiological and psychological behavior of man, appears to be a reasonable assumption. The connection between this assumption and changing solar conditions is at present highly speculative but may be taken sufficiently seriously as to open up definite fields of investigation.

"Such of the preceding facts as have a definite scientific basis are sufficiently numerous to lead us to believe that the sun may have more far-reaching effects upon terrestrial affairs than we have been accustomed to suppose. Speculations are always entertaining, but if real progress is to be made, one cannot overemphasize caution against drawing conclusions which scientific evidence is not sufficient to justify. On the other hand, unwarranted dogmatism as to the nonexistence of some of the relationships between the sun and the earth upon which we have speculated is inconsistent with the spirit of openmindedness which looks toward the scientific conquest of the unknown."

Here our interview was interrupted by a sharp blast from the steam whistle as it brought the accustomed call, "All ashore that are going ashore!"

Just then a black cloud of smoke belched from the funnel, partly obscuring the afternoon sun. I glanced up. There in the middle of the red solar disk was a naked-eye sunspot.

"Speaking of sunspots," I said. "Look there!"

"Well, goodbye, Doctor. Thank you very much."

"Goodbye," I said, laughingly adding, "and may the sunspots be kind to you."

Appendix

Sunspot Numbers—Wolf and Wolfer*

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1749	58 0	62.6	70.0	55.7	85.0	83.5	94.8	66.3	75.9	75.5	158.6	85.2	80.9
1750	73.3	75.9	89.2	88.3	90.0	100.0	85.4	103.0	91.2	65.7	63.3	75.4	83.4
1751	70.0	43.5	45.3	56.4	60.7	50.7	66.3	59.8	23.5	23.2	28.5	44.0	47.7
1752	35.0	50.0	71.0	59.3	59.7	39.6	78.4	29.3	27.1	46.6	37.6	40.0	47.8
1753	44.0	32.0	45.7	38.0	36.0	31.7	22.0	39.0	28.0	25.0	20.0	6.7	30.7
1754	0.0	3.0	1.7	13.7	20.7	26.7	18.8	12.3	8.2	24.1	13.2	4.2	12.2
1755	10.2	11.2	6.8	6.5	0.0	0.0	8.6	3.2	17.8	23.7	6.8	20.0	9.6
1756	12.5	7.1	5.4	9.4	12.5	12.9	3.6	6.4	11.8	14.3	17.0	9.4	10.2
1757	14.1	21.2	26.2	30.0	38.1	12.8	25.0	51.3	39.7	32.5	64.7	33.5	32.4
1758	37.6	52.0	49.0	72.3	46.4	45.0	44.0	38.7	62.5	37.7	43.0	43.0	47.6
1759	48.3	44.0	46.8	47.0	49.0	50.0	51.0	71.3	77.2	59.7	46.3	57.0	54.0
1760	67.3	59.5	74.7	58.3	72.0	48.3	66.0	75.6	61.3	50.6	59.7	61.0	62.9
1761	70.0	91.0	80.7	71.7	107.2	99.3	94.1	91.1	100.7	88.7	89.7	46.0	85.9
1762	43.8	72.8	45.7	60.2	39.9	77.1	33.8	67.7	68.5	69.3	77.8	77.2	61.2
1763	56.5	31.9	34.2	32.9	32.7	35.8	54.2	26.5	68.1	46.3	60.9	61.4	45.1
1764	59.7	59.7	40.2	34.4	44.3	30.0	30.0	30.0	28.2	28.0	26.0	25.7	36.4
1765	24.0	26.0	25.0	22.0	20.2	20.0	27.0	29.7	16.0	14.0	14.0	13.0	20.9
1766	12.0	11.0	36.6	6.0	26.8	3.0	3.3	4.0	4.3	5.0	5.7	19,2	11.4
1767	27.4	30.0	43.0	32.9	29.8	33.3	21.9	40.8	42.7	44.1	54.7	53.3	37.8
1768	53.5	66.1	46.3	42.7	77.7	77.4	52.6	66.8	74.8	77.8	90.6	111.8	69.8
1769	73.9	64.2	64.3	96.7	73.6	94.4	118.6	120.3	148.8	158.2	148.1	112.0	106.1
1770	104.0	142.5	80.1	51.0	70.1	83.3	109.8	126.3	104.4	103.6	132.2	102.3	100.8
1771	36.0	46.2	46.7	64.9	152.7	119.5	67.7	58.5	101.4	90.0	99.7	95.7	81.6
1772	100.9	90.8	31.1	92.2	38.0	57.0	77.3	56.2	50.5	78.6	61.3	64.0	66.5
1773	54.6	29.0	51.2	32.9	41.1	28.4	27.7	12.7	29.3	26.3	40.9	43.2	34.8
1774	46.8	65.4	55.7	43.8	51.3	28.5	17.5	6.6	7.9	14.0	17.7	12.2	30.6
1775	4.4	0.0	11.6	11.2	3.9	12.3	1.0	7.9	3.2	5.6	15.1	7.9	7.0
1776	21.7	11.6	6.3	21.8	11.2	19.0	1.0	24.2	16.0	30.0	35.0	40.0	19.8
1777	45.0	36.5	39.0	95.5	80.3	80.7	95.0	112.0	116.2	106.5	146.0	157.3	92.5
1778	177.3	109.3	134.0	145.0	238.9	171.6	153.0	140.0	171.7	156.3	150.3	105.0	154.4
1779	114.7	165.7	118.0	145.0	140.0	113.7	143.0	112.0	111.0	124.0	114.0	110.0	125.9
1780	70.0	98.0	98.0	95.0	107.2	88.0	86.0	86.0	93.7	77.0	60.0	58.7	84.8

SUNSPOT NUMBERS—WOLF AND WOLFER.*—(*Continued*)

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1781	98.7	74.7	53.0	68.3	104.7	97.7	73.5	66.0	51.0	27.3	67.0	35.2	68.1
1782	54.0	37.5	37.0	41.0	54.3	38.0	37.0	44.0	34.0	23.2	31.5	30.0	38.5
1783	28.0	38 7	26.7	28.3	23.0	25.2	32.2	20.0	18.0	8.0	15.0	10.5	22.8
1784	13.0	8.0	11.0	10.0	6.0	9 0	6.0	10.0	10.0	8.0	17.0	14.0	10.2
1785	6.5	8.0	9.0	15.7	20.7	26.3	36.3	20.0	32.0	47.2	40.2	27.3	24.1
1786	37.2	47.6	47.7	85.4	92.3	59.0	83.0	89.7	111.5	112.3	116.0	112.7	82.9
1787	134.7	106.0	87.4	127.2	134.8	99.2	128.0	137.2	157.3	157.0	141.5	174.0	132.0
1788	138.0	129.2	143.3	108.5	113.0	154.2	141.5	136.0	141.0	142.0	94.7	129.5	130.9
1789	114.0	125.3	120.0	123.3	123.5	120.0	117.0	103.0	112.0	89.7	134.0	135.5	118.1
1790	103.0	127.5	96.3	94.0	93.0	91.0	69.3	87.0	77.3	84.3	82.0	74.0	89.9
1791	72.7	62.0	74.0	77.2	73.7	64.2	71.0	43.0	66.5	61.7	67.0	66.0	66.6
1792	58.0	64.0	63.0	75.7	62.0	61.0	45.8	60.0	59.0	59.0	57.0	56.0	60.0
1793	56.0	55.0	55.5	53.0	52.3	51.0	50.0	29.3	24.0	47.0	44.0	45.7	46.9
1794	45.0	44.0	38.0	28.4	55.7	41.5	41.0	40.0	11.1	28.5	67.4	51.4	41.0
1795	21.4	39.9	12.6	18.6	31.0	17.1	12.9	25.7	13.5	19.5	25.0	18.0	21.3
1796	22.0	23.8	15.7	31.7	21.0	6.7	26.9	1.5	18.4	11.0	8.4	5.1	16.0
1797	14.4	4.2	4.0	4.0	7.3	11.1	4.3	6.0	5.7	6.9	5.8	3.0	6.4
1798	2.0	4.0	12.4	1.1	0.0	0.0	0.0	3.0	2.4	1.5	12.5	9.9	4.1
1799	1.6	12.6	21.7	8.4	8.2	10.6	2.1	0.0	0.0	4.6	2.7	8.6	6.8
1800	6.9	9.3	13.9	0.0	5.0	23.7	21.0	19.5	11.5	12.3	10.5	40.1	14.5
1801	27.0	29.0	30.0	31.0	32.0	31.2	35.0	38.7	33.5	32.6	39.8	48.2	34.0
1802	47.8	47.0	40.8	42.0	44.0	46.0	48.0	50.0	51.8	38.5	34.5	50.0	45.0
1803	50.0	50.8	29.5	25.0	44.3	36.0	48.3	34.1	45.3	54.3	51.0	48.0	43.1
1804	45.3	48.3	48.0	50.6	33.4	34.8	29.8	43.1	53.0	62.3	61.0	60.0	47.5
1805	61.0	44.1	51.4	37.5	39.0	40.5	37.6	42.7	44.4	29.4	41.0	38.3	42.2
1806	39.0	29.6	32.7	27.7	26.4	25.6	30.0	26.3	24.0	27.0	25.0	24.0	28.1
1807	12.0	12.2	9.6	23.8	10.0	12.0	12.7	12.0	5.7	8.0	2.6	0.0	10.1
1808	0.0	4.5	0.0	12.3	13.5	13.5	6.7	8.0	11.7	4.7	10.5	12.3	8.1
1809	7.2	9.2	0.9	2.5	2.0	7.7	0.3	0.2	0.4	0.0	0.0	0.0	2.5
1810	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1811	0.0	0.0	0.0	0.0	0.0	0.0	6.6	0.0	2.4	6.1	0.8	1.1	1.4
1812	11.3	1.9	0.7	0.0	1.0	1.3	0.5	15.6	5.2	3.9	7.9	10.1	5.0
1813	0.0	10.3	1.9	16.6	5.5	11.2	18.3	8.4	15.3	27.8	16.7	14.3	12.2
1814	22.2	12.0	5.7	23.8	5.8	14.9	18.5	2.3	8.1	19.3	14.5	20.1	13.9
1815	19.2	32.2	26.2	31.6	9.8	55.9	35.5	47.2	31.5	33.5	37.2	65.0	35.4
1816	26.3	68.8	73.7	58.8	44.3	43.6	38.8	23.2	47.8	56.4	38.1	29.9	45.8
1817	36.4	57.9	96.2	26.4	21.2	40.0	50.0	45.0	36.7	25.6	28.9	28.4	41.1
1818	34.9	22.4	29.7	34.5	53.1	36.4	28.0	31.5	26.1	31.7	10.9	25.8	30.4
1819	32.5	20.7	3.7	20.2	19.6	35.0	31.4	26.1	14.9	27.5	25.1	30.6	23.9
1820	19.2	26.6	4.5	19.4	29.3	10.8	20.6	25.9	5.2	9.0	7.9	9.7	15.7

SUNSPOT NUMBERS—WOLF AND WOLFER.*—(*Continued*)

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1821	21.5	4.3	5.7	9.2	1.7	1.8	2.5	4.8	4.4	18.8	4.4	0.0	6.6
1822	0.0	0.9	16.1	13.5	1.5	5.6	7.9	2.1	0.0	0.4	0.0	0.0	4.0
1823	0.0	0.0	0.6	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	20.4	1.8
1824	21.6	10.8	0.0	19.4	2.8	0.0	0.0	1.4	20.5	25.2	0.0	0.8	8.5
1825	5.0	15.5	22.4	3.8	15.4	15.4	30.9	25.4	15.7	15.6	11.7	22.0	16.6
1826	17.7	18.2	36.7	24.0	32.4	37.1	52.5	39.6	18.9	50.6	39.5	68.1	36.3
1827	34.6	47.4	57.8	46.0	56.3	56.7	42.9	53.7	49.6	57.2	48.2	46.1	49 7
1828	52.8	64.4	65.0	61.1	89.1	98.0	54.3	76.4	50.4	34.7	57.0	46.9	62.5
1829	43.0	49.4	72.3	95.0	67.5	73.9	90.8	78.3	52.8	57.2	67.6	56.5	67.0
1830	52.2	72.1	84.6	107.1	66.3	65.1	43.9	50.7	62.1	84.4	81.2	82.1	71 0
1831	47.5	50.1	93.4	54.6	38.1	33.4	45.2	54.9	37.9	46.2	43.5	28.9	47.8
1832	30.9	55.5	55.1	26.9	41.3	26.7	13.9	8.9	8.2	21.1	14.3	27.5	27.5
1833	11.3	14.9	11.8	2.8	12.9	1.0	7.0	5.7	11.6	7.5	5.9	9.9	8.5
1834	4.9	18.1	3.9	1.4	8.8	7.8	8.7	4.0	11.5	24.8	30.5	34.5	13.2
1835	7.5	24.5	19.7	61.5	43.6	33.2	59.8	59.0	100.8	95.2	100.0	77.5	56.9
1836	88.6	107.6	98.1	142.9	111.4	124.7	116.7	107.8	95.1	137.4	120.9	206.2	121.5
1837	188.0	175.6	134.6	138.2	111.3	158.0	162.8	134.0	96.3	123.7	107.0	129.8	138.3
1838	144.9	84.8	140.8	126.6	137.6	94.5	108.2	78.8	73.6	90.8	77.4	79.8	103.2
1839	107.6	102.5	77.7	61.8	53.8	54.6	84.7	131.2	132.7	90.8	68.8	63.6	85.8
1840	81.2	87.7	55.5	65.9	69.2	48.5	60.7	57.8	74.0	49.8	54.3	53.7	63.2
1841	24.0	29.9	29.7	42.6	67.4	55.7	30.8	39.3	35.1	28.5	19.8	38.8	36.8
1842	20.4	22.1	21.7	26.9	24.9	20.5	12.6	26.5	18.5	38.1	40.5	17.6	24.2
1843	13.3	3.5	8.3	8.8	21.1	10.5	9.5	11.8	4.2	5.3	19.1	12.7	10.7
1844	9.4	14.7	13.6	20.8	12.0	3.7	21.2	23.9	6.9	21.5	10.7	21.6	15.0
1845	25.7	43.6	43.3	56.9	47.8	31.1	30.6	32.3	29.6	40.7	39.4	59.7	40.1
1846	38.7	51.0	63.9	69.2	59.9	65.1	46.5	54.8	107.1	55.9	60.4	65.5	61.5
1847	62.6	44.9	85.7	44.7	75.4	85.3	52.2	140.6	161.2	180.4	138.9	109.6	98.5
1848	159.1	111.8	108.9	107.1	102.2	123.8	139.2	132.5	100.3	132.4	114.6	159.9	124.3
1849	156.7	131.7	96.5	102.5	80.6	81.2	78.0	61.3	93.7	71.5	99.7	97.0	95.9
1850	78.0	89.4	82.6	44.1	61.6	70.0	39.1	61.6	86.2	71.0	54.8	60.0	66.5
1851	75.5	105.4	64.6	56.5	62.6	63.2	36.1	57.4	67.9	62.5	50.9	71.4	64.5
1852	68.4	67.5	61.2	65.4	54.9	46.9	42.0	39.7	37.5	67.3	54.3	45.4	54.2
1853	41.1	42.9	37.7	47.6	34.7	40.0	45.9	50.4	33.5	42.3	28.8	23.4	39.0
1854	15.4	20.0	20.7	26.4	24.0	21.1	18.7	15.8	22.4	12.7	28.2	21.4	20.6
1855	12.3	11.4	17.4	4.4	9.1	5.3	0.4	3.1	0.0	9.7	4.2	3.1	6.7
1856	0.5	4.9	0.4	6.5	0.0	5.0	4.6	5.9	4.4	4.5	7.7	7.2	4.3
1857	13.7	7.4	5.2	11.1	29.2	16.0	22.2	16.9	42.4	40.6	31.4	37.2	22.8
1858	39.0	34.9	57.5	38.3	41.4	44.5	56.7	55.3	80.1	91.2	51.9	66.9	54.8
1859	83.7	87.6	90.3	85.7	91.0	87.1	95.2	106.8	105.8	114.6	97.2	81.0	93.8
1860	81.5	88.0	98.9	71.4	107.1	108.6	116.7	100.3	92.2	90.1	97.9	95.6	95.7

Sunspot Numbers—Wolf and Wolfer.*—(*Continued*)

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1861	62.3	77.8	101.0	98.5	56.8	87.8	78.0	82.5	79.9	67.2	53.7	80.5	77.2
1862	63.1	64.5	43.6	53.7	64.4	84.0	73.4	62.5	66.6	42.0	50.6	40.9	59.1
1863	48.3	56.7	66.4	40.6	53.8	40.8	32.7	48.1	22.0	39.9	37.7	41.2	44.0
1864	57.7	47.1	66.3	35.8	40.6	57.8	54.7	54 8	28.5	33.9	57.6	28.6	47.0
1865	48.7	39.3	39.5	29.4	34.5	33.6	26.8	37.8	21.6	17.1	24.6	12.8	30.5
1866	31.6	38.4	24.6	17.6	12.9	16.5	9.3	12.7	7.3	14.1	9.0	1.5	16.3
1867	0.0	0.7	9.2	5.1	2.9	1.5	5.0	4.9	9.8	13.5	9.3	25.2	7.3
1868	15.6	15.8	26.5	36 6	26.7	31.1	28.6	34.4	43.8	61.7	59.1	67.6	37.3
1869	60.9	59.3	52.7	41.0	104.0	108.4	59.2	79.6	80.6	59.4	77.4	104.3	73.9
1870	77.3	114.9	159.4	160.0	176.0	135.6	132.4	153.8	136.0	146.4	147.5	130.0	139.1
1871	88.3	125.3	143.2	162.4	145.5	91.7	103.0	110.0	80.3	89.0	105.4	90.3	111.2
1872	79.5	120.1	88.4	102.1	107.6	109.9	105.5	92.9	114.6	103.5	112.0	83.9	101.7
1873	86.7	107.0	98.3	76.2	47.9	44.8	66.9	68.2	47.5	47.4	55.4	49.2	66.3
1874	60.8	64.2	46.4	32.0	44.6	38.2	67.8	61.3	28.0	34.3	28.9	29.3	44.7
1875	14.6	22.2	33.8	29.1	11.5	23.9	12.5	14.6	2.4	12.7	17.7	9.9	17.1
1876	14.3	15.0	31.2	2.3	5.1	1.6	15.2	8.8	9.9	14.3	9.9	8.2	11.3
1877	24.4	8.7	11.7	15.8	21.2	13.4	5.9	6.3	16.4	6.7	14.5	2.3	12.3
1878	3.3	6.0	7.8	0.1	5.8	6.4	0.1	0.0	5.3	1.1	4.1	0.5	3.4
1879	0.8	0.6	0.0	6.2	2.4	4.8	7.5	10.7	6.1	12.3	12.9	7.2	6.0
1880	24.0	27.5	19.5	19.3	23.5	34.1	21.9	48.1	66.0	43.0	30.7	29.6	32.3
1881	36.4	53.2	51.5	51.7	43.5	60.5	76.9	58.0	53.2	64.0	54.8	47.3	54.3
1882	45.0	69.3	67.5	95.8	64.1	45.2	45.4	40.4	57.7	59.2	84.4	41.8	59.7
1883	60.6	46.9	42.8	82.1	32.1	76.5	80.6	46.0	52.6	83.8	84.5	75.9	63.7
1884	91.5	86.9	86.8	76.1	66.5	51.2	53.1	55.8	61.9	47.8	36.6	47.2	63.5
1885	42.8	71.8	49.8	55.0	73.0	83.7	66.5	50.0	39.6	38.7	33.3	21.7	52.2
1886	29.9	25.9	57.3	43.7	30.7	27.1	30.3	16.9	21.4	8.6	0.3	12.4	25.4
1887	10.3	13.2	4.2	6.9	20.0	15.7	23.3	21.4	7.4	6.6	6.9	20.7	13.1
1888	12.7	7.1	7.8	5.1	7.0	7.1	3.1	2.8	8.8	2.1	10.7	6.7	6.8
1889	0.8	8.5	7.0	4.3	2.4	6.4	9.7	20.6	6.5	2.1	0.2	6.7	6.3
1890	5.3	0.6	5.1	1.6	4.8	1.3	11.6	8.5	17.2	11.2	9.6	7.8	7.1
1891	13.5	22.2	10.4	20.5	41.1	48.3	58.8	33.2	53.8	51.5	41.9	32.2	35.6
1892	69.1	75.6	49.9	69.6	79.6	76.3	76.8	101.4	62.8	70.5	65.4	78.6	73.0
1893	75.0	73.0	65.7	88.1	84.7	88.2	88.8	129.2	77.9	79.7	75.1	93.8	84.9
1894	83.2	84.6	52.3	81.6	101.2	98.9	106.0	70.3	65.9	75.5	56.6	60.0	78.0
1895	63.3	67.2	61.0	76.9	67.5	71.5	47.8	68.9	57.7	67.9	47.2	70.7	64.0
1896	29.0	57.4	52.0	43.8	27.7	49.0	45.0	27.2	61.3	28.4	38.0	42.6	41.8
1897	40.6	29.4	29.1	31.0	20.0	11.3	27.6	21.8	48.1	14.3	8.4	33.3	26.2
1898	30.2	36.4	38.3	14.5	25.8	22.3	9.0	31.4	34.8	34.4	30.9	12.6	26.7
1899	19.5	9.2	18.1	14.2	7.7	20.5	13.5	2.9	8.4	13.0	7.8	10.5	12.1
1900	9.4	13.6	8.6	16.0	15.2	12.1	8.3	4.3	8.3	12.9	4.5	0.3	9.5

SUNSPOT NUMBERS—WOLF AND WOLFER.*—(*Continued*)

Date	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1901	0.2	2.4	4.5	0.0	10 2	5.8	0.7	1.0	0.6	3.7	3.8	0.0	2.7
1902	5.2	0.0	12.4	0.0	2.8	1.4	0.9	2.3	7.6	16.3	10.3	1.1	5.0
1903	8.3	17.0	13.5	26.1	14.6	16.3	27.9	28.8	11.1	38.9	44.5	45.6	24.4
1904	31.6	24.5	37.2	43.0	39.5	41.9	50.6	58.2	30.1	54.2	38.0	54.6	42.0
1905	54.8	85.8	56.5	39.3	48.0	49.0	73.0	58.8	55.0	78.7	107.2	55.5	63 5
1906	45.5	31.3	64.5	55.3	57.7	63.2	103.3	47.7	56.1	17.8	38.9	64.7	53.8
1907	76.4	108.2	60.7	52.6	43.0	40.4	49.7	54.3	85.0	65.4	61.5	47 3	62.0
1908	39.2	33.9	28.7	57.6	40.8	48.1	39 5	90.5	86.9	32.3	45.5	39.5	48.5
1909	56.7	46.6	66.3	32.3	36.0	22.6	35.8	23.1	38.8	58.4	55.8	54.2	43.9
1910	26.4	31.5	21.4	8.4	22.2	12.3	14.1	11.5	26.2	38.3	4.9	5.8	18 6
1911	3.4	9.0	7.8	16 5	9.0	2.2	3.5	4.0	4.0	2.6	4.2	2.2	5.7
1912	0.3	0.0	4.9	4.5	4.4	4.1	3.0	0.3	9.5	4.6	1.1	6.4	3.6
1913	2.3	2 9	0.5	0.9	0.0	0.0	1.7	0.2	1.2	3.1	0.7	3.8	1.4
1914	2.5	2.6	3.1	17.3	5.3	11.4	5.4	7.8	12.8	8.1	16.1	22.2	9.6
1915	23.0	42.3	38.8	41.3	33.0	68.8	71.6	69.6	49.5	53.5	42.5	34.5	47.4
1916	45.3	55.4	67.0	71.8	74.5	67.7	53.5	35.2	45.1	50.7	65.6	53.0	55.4
1917	74.7	71.9	94.8	74.7	114.1	114.9	119.8	154.5	129.4	72.2	96.4	129.3	103.9
1918	96.0	65.3	72.2	80.5	76.7	59.4	107.6	101.7	79.9	85.0	83.4	59.2	80.6
1919	48.1	79.5	66.5	51.8	88.1	111.2	64.7	69.0	54.7	52.8	42.0	34.9	63.6
1920	57.3	50.9	71.9	14.3	33.7	38.8	26.5	18.6	38.7	48.8	24.6	39.9	38.7
1921	28.8	27.6	27.5	30.5	22.3	34.5	42.4	20.8	16.7	16.1	13.4	15.7	24.7
1922	10.2	27.9	60.0	11.4	7.7	5.8	9.7	5.3	5.2	8.1	6.7	18.7	14.7
1923	4.5	1.5	3.3	6.1	3.2	9.1	3.5	0.5	13.2	11.6	10.0	2.8	5.8
1924	0.5	5.1	1.8	11.3	20.8	24.0	28.1	19.3	25.1	25.6	22.5	16.5	16.7
1925	5.5	23.2	18.0	31.7	42.8	47.5	38.5	37.9	60.2	69.2	58.6	98.6	44.3
1926	71.8	70.0	62.5	38.5	64.3	73.5	52.3	61.6	60.8	71.5	60.5	79.4	63.9
1927	81.6	93.0	69.6	93.5	79.1	59.1	54.9	53.8	68.4	63.1	67.2	45.2	69.0
1928	83.5	73.5	85.4	80.6	76.9	91.4	98.0	83.8	89 7	61.4	50.3	59.0	77.8
1929	68.9	64.1	50.2	52.8	58.2	71.9	70.2	65.8	34.4	54.0	81.1	108.0	65.0
1930	65.3	49.2	35.0	38.2	36.9	28.8	21.9	24.9	32.1	34.4	35.6	25.8	34.0
1931	14.6	43.1	30.0	31.2	24.6	15.3	17.4	13.0	19.0	10.0	18.7	17.8	21.2
1932	12.1	10.6	11.2	11.2	17.9	22.2	9.6	6.8	4.0	8.9	8.2	11.0	11.1
1933	12.3	22.2	10.1	2.9	3.2	5.2	2.8	0.2	5.1	3.0	0.6	0.3	5.6
1934	3.4	7.8	4.3	11.3	19.7	6.7	9.3	8.3	4.0	5.7	8.7	15.4	8.7
1935	18.9	20.5	23.1	12.2	27.3	45.7	33.9	30.1	42.1	53.2	64.2	61.5	36.1
1936	60.4	73.8	77.7	77.1	54.1	70.5	52.4	67.6	75.1	85.5	113.4	117.5	77.1
1937	137.0	130.3	85.0	113.5	116.9	130.3	143.9						

* From revised numbers by A. Wolfer in *Monthly Weather Review*, Vol. 30 and subsequent volumes. Values for 1937 are provisional numbers supplied by Zurich, Switzerland, Observatory.